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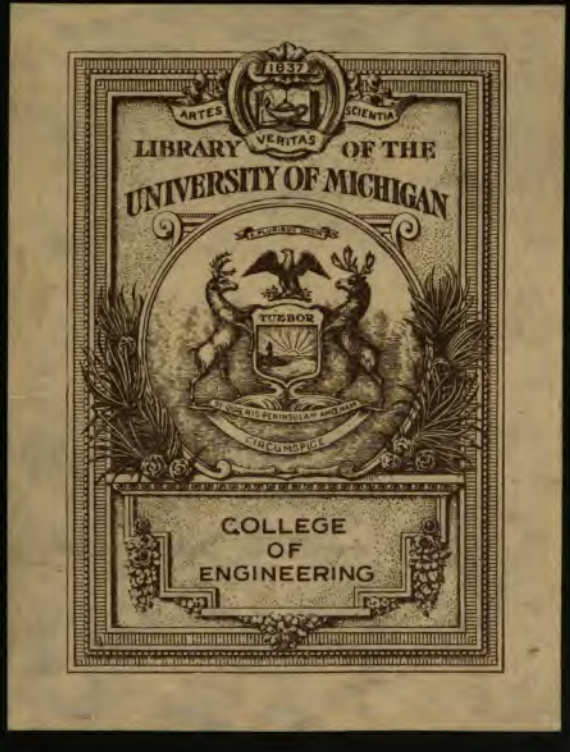
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SESSION 1906-7.

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INAUGURAL ADDRESS

(51st Discussion Session)

BY THE PRESIDENT,

Mr. W. Henry Hunter, M.Inst.C.E.,

DELIVERED SATURDAY, 27th OCTOBER, 1906.

At the time when my distinguished predecessor, Mr. Matthews, acting on your behalf, installed me in the chair which he had just vacated, I attempted to express my sense of the high honour which you had done to me in electing me to the office of President of this Association. I will not, therefore, now occupy your time in repeating that expression, but wish to be allowed to place it on record, and to add thereto my cordial thanks for the consideration and for the assistance which I have received from the Council and from the Officers of the Association in the period which has elapsed since I began to undertake the duties of the Presidential Office—an office which I have found to be by no means of the nature of a sinecure.

It would be out of place for me in this address to trench upon the thorny area of party politics—even if I desired to do so—but having in view the critical character of the period at which we have arrived, I do ask to be permitted to make some observations to you of a *quasi* political sort and that because (1) the matters themselves are of the first importance to all engineers and (2) it has happened that the commencement of the second half century in the life of this Association has synchronised with a new departure of a momentous character in the political life of this Country.

We have just left our first Jubilee behind us, and together with that experience we have seen a new Parliament come into

being, and with the new Parliament a new Government has assumed the conduct of affairs in the land, and to a certain extent in the Empire. This of itself would call for no remark on the present occasion. We have seen many new Parliaments and have witnessed the assumption of office by many new Governments. But this new Parliament has marked the inauguration of a new era—there has been nothing like it since the incoming of the Parliament which followed the Reform Bill of 1832—an era of class legislation, of legislation in the interests of the employed and in prejudice of the interests of the employers; so that as an earnest of that which is to follow, we have in course of passage through the House of Commons (1) a Trades' Disputes Bill, which provides that Trade Societies shall be placed in an impregnable position, that is to say, shall be rendered irresponsible for the acts of their members or even of their accredited agents, and that picketing and other means of "peaceable persuasion" shall be legalized by Statute, and (2) a Workman's Compensation Act Amendment Bill through which almost every barrier between the workmen's claim and the employer's pocket, which now exists, will be swept away.

The change in the constitution of the House of Commons brought about at the last General Election has, unfortunately enough, rendered legislation of this sort inevitable, and conflict with the inevitable is as futile and as exhausting as Mrs. Partington's dogged and determined but bootless battle with the Atlantic Ocean. In the last House of Commons there were eleven direct representatives of the labour interest. In the present House there are fifty-one. But the proportion between these numbers is very far from representing the change in the conditions which has taken place, as not merely on the Government benches or on the benches occupied by the Independent Labour Party, but throughout the whole House an over-whelming majority of members have pledged themselves,

in their anxiety to secure election to the House, to favour and to further class legislation—legislation for the workman and against the employer.

The all important question before us to-day is as to whether this change will prove to be of a permanent sort, or whether it is a mere temporary aberration, to be followed sooner or later by a marked movement of re-action? In searching for an answer to the question mere opinion can be of no value to us, the answer must be one upon which we can rely and upon which we can base our course of future procedure, and I propose to submit to you certain considerations which I suggest should be taken into account in framing that answer.

The history of civilisation is the record of the evolution of the common mind of humanity, and may be summarised in a general way as the record of the effort, in most cases the unconscious effort, of that which is best and highest in man to counteract the operation of the law of the survival of the fittest—that is to say of the destruction of the weaker to make room for the stronger—which has obtained in the brute creation, and which has had such far-reaching influence even in the racial struggles of mankind.

Civilized humanity as influenced by Christianity, has in effect agreed that the race shall not always be to the swift nor the battle to the strong, but that the lame man shall have his chance and the feeble man his opportunity. For instance, Christian civilisation has made and is making strenuous effort to stamp out infanticide, whether direct or indirect, to ensure the protection of the weak and puny child, and to secure for that child the chance in the struggle for existence which otherwise would have been denied to it.

Again civilisation has, perhaps tardily, but still effectively, intervened to save the wrecks of native races and the remnants of aboriginal tribes from extinction, the conscience of enlightened

humanity having revolted against the simple and successful methods of extermination which held sway at the time when Spaniards and Portugese forced their way into Central and Southern America, and when Britons first colonized North America, Australia and New Zealand, so that we ourselves boast that wherever the British flag flies the native not only receives justice but finds protection against stronger and more vigorous personalities, and where necessary, against himself; for civilization, using the word for want of a better to describe human progress in the line of ethics and of order, stands for the protection, by artificial means—that is to say by means of art and man's device—of the weaker against the stronger, in other words for the redress of inequality in the social balance.

Progress in the line indicated is and must be like that of the tidal wave, it is irresistible. Checks in the advance there have been and checks there will no doubt be again, but the balance of the plus and minus sum will always be on the plus side; and few will deny that the would be legislators who, at the late General Election pledged themselves to support the claims of labour in the Houses of Parliament, did no more than yield themselves to an overwhelming force by which they were encompassed and—in many cases possibly without knowing what they did or where they were going—adapt themselves to their environment.

So far then as class legislation is legislation in favour of the weaker elements in the body politic as against the more powerful elements in that body, I am afraid that a true appreciation of the circumstances will lead to the conclusion that the change which we have witnessed will prove to be of a permanent character, and that so far as the employers in the United Kingdom are concerned, wisdom and sound judgment will be found in the line of the acceptance of the situation and in the adaptation of methods in order to meet the alteration of the economic

surroundings which has occurred; seeing that such alteration has not been due to the somewhat wild oratory of vociferous demagogues to which we have become accustomed, but to the enlargement of the conceptions of the human mind and to the raising of the standard of the human ideal which have been in process of development for centuries past, and which have borne fruit amongst us upon whom the ends of the ages are come.

Another consideration will, I think, lead to the same conclusion regarding the inevitable character and the permanent nature of the change, and will further lead us to anticipate other and perhaps more momentous changes.

The consideration is one which has occupied the attention of very few and which has been absolutely ignored by the genera public. Yet it is of world wide and paramount importance, and the time cannot be far distant when that importance will be recognised as being supreme amongst mundane motives of action.

The consideration is that of the phenomenal rate at which the population of the earth is increasing; and reference thereto will not, I hope, be accounted as out of place in this address seeing first, that it is but turning from the effect of Christian civilization upon the human mind to that of the same great cause upon human life, and secondly, that the consideration is one by which engineers, of all men, will be most vitally affected.

The Nineteenth Century is rapidly fading into the haze of history. Much has been written concerning its experiences and its events, and much more will be written yet; but amongst all the comments upon the course of the nineteenth century and the reflections upon the developments which emerged during that course, I, at any rate, have seen no observation made upon the fact which stands out so salient in its records, and which is that it appears certain that between the years 1800 and 1900 the population of the Globe was doubled.

I say that it appears certain that this doubling of the population took place; I admit that it is difficult to procure evidence which is absolutely conclusive, but I feel sure that any member of the Association who will set himself to the task of analysing and condensing the statistics which are available will agree that it is within the mark to say that in the year 1800 the world's population was under 800 millions, and that in 1900 the population was at least 1,600 millions; an increase of fully 100 per cent.

This computation is certainly not immoderate, in support of which assertion the accurate returns of the first census of the population of England and Wales, which took place in 1801, and of the eleventh census, taken in 1901, may be cited. The respective totals were: in 1801, 8,892,536 souls and in 1901, 32,627,843 souls, or in other words in England and Wales the population was nearly quadrupled in the nineteenth century, in which fact much of the true inwardness of the problem of the unemployed, in Manchester and elsewhere, will be found to lie.

It may be that the figures relating to the increase of the population of the globe taken alone, seem only to be figures, such as those in which the distance of the earth from the sun, or of the sun from the north star may be described, and that they do not convey much to the mind of practical men who are more or less absorbed in the every day business of life. But in the words of a famous character who will survive when we have all passed away, "I want to make your flesh creep," and therefore will try to make them more expressive and impressive by adding to them one other figure of a highly controversial sort, viz: that relating to the length of the period which the human race occupied in attaining to the round figure of 800 millions of souls which I have assumed to be the population of the world in the year 1800.

There is a wide difference of opinion as to the time which has elapsed since man first appeared on the earth. Traditional interpretation of the scriptural record has fixed the term at about 6,000 years, while geologists and archæologists contend that the term must be measured not by thousands but by hundreds of thousands of years. It is not necessary for my purpose to choose between the divergent claims, as the records contained in the book of Genesis and wide spread legend—legend almost universal in scope if we except, and the exception is a notable one, the ancient Egyptian lands—agree in their testimony to the occurrence of a devastating catastrophe through which the human family was reduced to very small limits, and which occurred before the Akkadian race settled in Mesopotamia, which was almost certainly more than 6,000 years ago.

Let us assume, for the sake of simplicity, in the pursuit of our present purpose that the catastrophe to which I have referred, the Deluge, took place some 6,000 years before the year of our Lord 1800, that at that time the human race was reduced almost to the vanishing point, that in 60 centuries therefrom the race numbered 800 millions of persons, and that in 61 centuries it numbered 1,600 millions. Now translate these figures into engineering language. Sir W. H. Preece said but recently that engineers think in curves: treat therefore the years as ordinates and the souls as abscissæ, and plot the curve, and when you have plotted it carry on the line for another century, and see whether the estimate of the world's population, at which you will thus arrive, will or will not be impressive as well as expressive.

If instead of producing the curve in a line of harmonic development, it be assumed arbitrarily that the point of maximum increase has been reached, and that the production should be on a line tangential to the terminal length of the curve, the result will still be amongst the things which pass all understanding.

But there is no ground for the assumption, on the contrary the census returns for England and Wales afford basis for presuming that the rate of increase will be accelerated rather than decreased, as the effects of civilisation become more widely extended, more universally felt.

Modern civilization diminishes the birth-rate in any country, the birth rate in this country is steadily declining, but diminishes the death rate in a much greater ratio; it protects the women and defends the children, and reduces to a degree, which it is difficult for us to appreciate, the loss of human life due to war, pestilence, and famine.

I will venture on one striking example as illustrative of this argument. In the fourteenth century the Far East, Western Asia, and the Continent of Europe suffered from the ravages due to a visitation of plague, which appears to have been of the bubonic type and which was commonly known as the "Black Death."

That dread visitant reached this country in the year 1348 Edward the Third was then King, and the population of England and Wales numbered about four millions. By the year 1350, two millions of the people—that is to say one-half of the population—were dead. The proportion between the number who had died of plague and the number who had died of fright can never be ascertained, but the fact remains that in two years half of the population was swept away. On the Continent it is said that 25 millions of people perished; Professor Thorold Rogers is of opinion that the estimate is rather below than above the mark—while the loss in Asia can only be imagined, no one has ventured to compute it.

Compare with that experience, an experience of our own in respect of visitation of plague in Great Britain. Six or seven years ago bubonic plague was again imported into this island, and terrible as it sounds men died of plague in a northern city in

our land. There was no panic, though there certainly was considerable sensation, as the public mind felt satisfied that the capacity and the competency of sanitary science, operating amongst civilized conditions were sufficient to cope with and to overcome even so powerful an enemy. The confidence was justified. Out of a great population crowded together in anything but ideal conditions, twelve persons, and twelve only, died.

If the present population of Great Britain had been living under the conditions which obtained here in the fourteenth century, there is no reason to doubt that the experience of 1850 would have been repeated, and one-half of the people, *i.e.* some 20 millions of persons, would have been cut off from the land of the living.

The questions relating to the elimination of the waste due to the three terrible scourges to humanity to which I have already referred—war, pestilence and famine—have demanded, and have received, and still demand and receive the attention of the noblest minds and the highest intellects amongst men, who, working in many fields and in varied branches of widely extended effort, have already attained much, so that truly great and beneficent changes in the conditions of human existence have been effected through which human life has been prolonged. But there is more to follow; there is no end in sight so far as the changes which are in progress are concerned, and the overwhelming problem which must force itself upon statesmen and other leaders of men, will be as to the possibility of sustaining the lives which under wilder and rougher conditions would have been wiped out, but which under the benign influences of Christian civilization have been and will be preserved, or in other words, as to the possibility of obtaining sufficient food from the earth for the maintenance of its rapidly increasing inhabitants.

The time at which that overwhelming problem will begin to make its weight felt is near enough for us to interest ourselves in it. During the nineteenth century the increase in the population was more than balanced by the increase in the wheat bearing areas of the globe, which took place, and which was due to the inclusion in those areas of vast virgin prairies and pampas in North and South America, which have with comparatively little effort towards cultivation, and with the expenditure of but little labour, yielded food which has sustained millions of people at distances of thousands of miles; as it happened that concurrently with the increase of the wheat bearing area greatly increased facilities for cheap carriage were provided by means of trans-continental railways, inland waterways, and trans-oceanic steamers.

The ultimate possibilities of these lands will, however, be reached before very long. There is but a comparatively small area of virgin soil waiting for development in the United States of America, though in Western Canada and in South America there are still great tracts available; and it is highly significant that in 1904 the United States, so far from exporting vast quantities as heretofore, quantities which helped to feed the people in this and other lands, were in the markets as buyers of grain, and were obliged to import wheat for the supply of their own people.

Can this circumstance be regarded as anything less serious than the beginning of the end, the end of the economic conditions to which we have grown accustomed and the ushering in of a new era which must by way of slow, perhaps insensible development environ us and our successors?

I hesitate—I shrink from any suggestion of reply to that question—I have before my mind the fate which a perverse progress of events has brought upon an implied prediction uttered by a highly esteemed predecessor in this chair, a President of

this Association, who carried away by the exhilarating character of his audience and by the loftiness of the themes which he had been discussing, and not having the fear of the future before his eyes, proceeded as follows in his inaugural address:

"I run the risk of being accused of descending from the sublime to the ridiculous when I name that the old idea of a ship canal from Liverpool to Manchester is being revived."

Forecasts, whether of the weather or of anything else, have a way of going wrong. My predecessor's forecast went wrong, so much so that for the second time a Chief Engineer of the Manchester Ship Canal has been elected by the Association to the office of President, and I have neither desire nor qualification for the assumption, in this address, of the prophet's mantle or the adoption of the prophet's role.

I should, however, remind you that questions, different in form but similar in sort to this, have been propounded on previous occasions by thinkers in this country and in other lands. In the course of a haphazard and perfunctory inspection of Exeter Cathedral some weeks ago, I was held up by an awakened interest as my eye lighted, unexpectedly, upon a tablet to the memory of Thomas Robert Malthus, in which the virtues and achievements of that well nigh forgotten philosopher were duly set forth. Malthus, who died in 1834, had not, could not have, the faintest idea of the changes which we have witnessed, or of the development in which we have taken part; but Malthus said, and said to a generation which decried him, that it was inevitable that the population of the earth must increase at a much greater rate than its food producing properties. He argued that population would increase in geometrical ratio while food supply could only increase in arithmetical ratio. Experience has shewn that the argument was not well founded, that the premises upon which the conclusion was based were insufficient, but experience has also

shewn that he was right as a matter of general principle, and in 1898 Sir William Crookes in his presidential address to the Bristol meeting of the British Association stated that "wheat eaters are multiplying faster than the wheat producing area, and fresh means will soon have to be found for increasing the supply of this commodity."

It seems as if the distinguished speaker failed to appreciate the rate at which wheat eaters are multiplying, as the way out of the difficulty which he suggested as likely to be found, would although of very great value when taken in conjunction with cognate efforts, of itself be insufficient to meet the case. Nevertheless, his words contain something of comfort and of hope, and I will begin my brief indication of measures which may be taken to increase the food supply of the earth by quoting them. "It is the chemist" said Sir William Crookes "who must come to the rescue of the threatened communities. It is through the laboratory that starvation may ultimately be be turned to plenty. By the artificial fixation of atmospheric nitrogen and its application to the soil, the yield of wheat can be increased three and four fold, and the day of famine will be postponed to so distant a period that we and our sons and our grandsons may legitimately live without undue solicitude for the future."

This dictum from the chair of the British Association for the advancement of science, although re-assuring in its optimism, can hardly be accepted as completely satisfactory. In the first place, starvation, even though it be ultimately turned into plenty, must not be allowed to intervene, and, in the second place, the deferring of undue solicitude for the future for a period represented by the lifetime of the grandson of a man of 74 years of age is not of itself sufficient to relieve us from anxiety.

Fortunately scientific workers in other directions can, and surely will, re-inforce the efforts of chemists and agriculturists

in the direction indicated, and will come to the aid of humanity (1) by increasing the supplies of foods from sources now available, and (2) by forming and developing food bearing areas in great districts which are now unproductive.

As an example of the possibilities under the first of these heads, naturalists tell us that the supply of valuable food now obtained in the form of fish from the rivers and from the seas may be largely increased if nature be stimulated and assisted in her efforts for the provision of food for the fish. Most of the tribes of edible fish feed either directly on algæ (sub-aqueous growths, commonly and somewhat contemptuously termed seaweed), or on insects which in their turn feed on the algæ, so that the stimulation of the algæ growth would bring about an increase in the food supply for these fish tribes and consequently an increase in the quantity of fish as food for human consumption.

The stimulation may be readily effected at small cost. We are assured that all which is required is the addition to the streams of carbonate of lime in suitable condition and in sufficient quantities. Carbonate of lime in the familiar forms of chalk, limestone and coral, exists almost anywhere in the globe, and if by feeding algæ, which in turn provide subsistence for insects, which feed fish, which supply food for human beings, chalk be utilized, indirectly, as part of the world's food supply, we may congratulate ourselves on another achievement due to scientific research.

But this is a comparatively small matter, serving here as an illustration of a principle; operations having much wider scope and productive of far greater results, may, and indeed must be undertaken for the increase of the food supply; operations in which engineers of all sorts must play a leading part. As I have said little more can be done in the way of absorbing virgin lands of fertile character within the area of cultivation and of

productiveness, as the greater part of such lands has already been absorbed and appropriated, but much may be done in the reclaiming of lands which once supported a great population but which have lapsed into barrenness, being peopled to-day only by wandering tribes of "undesirables," who are doing no good either for themselves or for others; who remain as the degenerate wreckage of a great past, semi-barbarians on the confines of civilization; migratory and predatory.

The lands referred to are known as the great Asiatic Steppes; for although a part of the vast area lies to the westward of the Ural range of mountains, by far the larger part is situated to the eastward of that great boundary of continents, and indeed forms no small proportion of the area of the whole continent of Asia.

These great and now almost useless tracts once supported a dense population. Mr. Archibald Colquhoun, whose authority on the matter, based as it is on personal investigation and on knowledge at first hand, is unquestioned, stated in a paper which he read before the Society of Arts in May, 1900, that "all over Central Asia we find traces of a civilization so old that it has been entirely forgotten, and nothing remains to tell us what were the races who dwelt there, or how they fell from their high estate. On the north bank of Syr Daria, all along the valley, are numerous ruins which mark the site of former cities; and legend says that this district, now a wilderness, with an occasional Russian fort or a small half-savage town, was once so densely populated that from Kashgar to the sea of Opal the nightingale could fly from branch to branch, and the cat walk from house-top to house-top."

That which has been before may be again, and it is obvious that whatever may be the political future of the Russian Empire or the outcome of the present upheaval in that state (which now holds sway throughout Central Asia), humanity cannot afford to allow so great a district to lie fallow, but that stern necessity

will compel the inclusion of the Steppes in the food producing area of the world.

In addition to the lands and countries which, once productive, are now, as Mr. Colquhoun says, "a wilderness," there are as all are aware, enormous areas of desert and barrenness on the earth which have never afforded any assistance towards the sustenance of mankind. The Sahara is the most familiar example, then follow Central Arabia and other tracts in Africa and in Asia as well as in Central Australia.

None of these apparently hopeless deserts can be accounted as beyond the reach or the power of a developing, a scientific, and an aggressive civilization, but it is clear that if the attacks of civilization upon them are to succeed, the attacks must be made in force, that is to say, that nations and peoples must unite in the effort, the thing is too great to be done in any other way.

At the present juncture it seems impossible to imagine that any earthly cause could persuade nations and peoples to act in unison for any purpose, the jealousies of States and the antagonisms of races prohibit any such wild imagining. Tennyson's "Vision of the World" when

> ".....the war-drums throbbed no longer, and the battle flags were furled
> In the Parliament of man, the federation of the world"

is as much a vision as ever it was, and has as little appearance of materialising; yet, although both States and men have lacked true wisdom and have failed in discernment; that which the sense of right has been unable to effect, the sense of hunger, or the fear of it, may bring to pass; and an international movement be rendered possible through which the earth's surface will be scientifically apportioned from the point of view of production, under which each area will be devoted to the purposes for which it is best suited and by which the wild steppes will be reclaimed, and the barren deserts rendered fruitful,

Engineering operations are growing greater and still more great year by year. In the construction of the Manchester Ship Canal some 51 millions of cubic yards of excavation were removed throughout the 35 miles of waterway, and this was at the time regarded as an extraordinary quantity.

In the sea level project for the Panama Canal, it is proposed—and I hope yet that the proposal will be carried into execution—that from the length through the Cordilleras, which form the divide between the Atlantic and the Pacific, and which only extends for nine miles out of a total length of 49 miles, no less than 175 millions of cubic yards of excavation shall be removed.

This great quantity has, unfortunately, staggered some of the ablest engineers in America, in the expressive language of their countrymen they have been "skeert" by it; but even this will be as child's play compared with the work which must be undertaken in order that the best may be made of the earth's surface. Afforestation, deforestation, irrigation, drainage, such operations with others doubtless of which we have never even dreamed, will do much to render barren lands fruitful, but they alone will be insufficient, as though in some cases the people may be taken to the food, in by far the greater number of instances the food must be taken to the people, and that implies that means of communication and of transportation by which all parts of the globe shall be connected together, even more closely and more directly than some parts are connected now, shall be provided.

It means further that manual labour must be superseded by mechanical efforts directed by human hands and minds, and that animal traction must give place to mechanical traction—horses are grain eaters and horses must disappear, they will not be worth their food—as neither the efforts of men nor the exertion of animals will be sufficient for the purposes of the

colossal undertaking which will be required and which our successors will, I have no doubt, boldly design and successfully execute.

Our successors, I say, because in this country, although the point at which united effort on the part of the smaller and more local community—the municipality—has become possible, the time when such effort shall be brought within the limits of practical politics for the larger community—the nation—is only beginning to come into sight, as many amongst us seem to have failed to recognise that individual effort, which has made the country what it is, has become insufficient for the carrying into execution of the great operations which are now required if we are to keep abreast of our neighbours, who are also our competitors and our rivals. Individual effort of a business sort, and not of a philanthropic kind, can only be put forth with a view to individual profit, and therefore will expend no capital except with the hope and prospect of direct return. On the other hand, the State or the municipality may put forth effort, and may and should expend capital for purposes which will, beyond question, be for the benefit, the advancement, the comfort, the health of the community, even though there be no expectation of direct return on the expenditure.

There are those who resent this doctrine. "Socialism—incipient Socialism" is the term which is attached to it. It is not for me here to argue either for or against the doctrine. I point out to you that whatever the doctrine may be the thing itself is not only impending, but is with us, and must grow and increase, for the smaller communities with which we are acquainted are now impelled, whether knowingly or unknowingly, along the course upon which they have entered, by the hard fact of the stupendous increase of the population which has taken place, and which is taking place, and to which I have ventured to call your attention.

The fact is that we are living in a period of transition, in a sort of psychic flux; the difficulties which are being encountered to-day are more or less of a temporary sort, and will give place to a new set of difficulties to-morrow, and I repeat that resistance would be as unwise as it would be futile; prudence and sound judgment require that those who, like the members of this Association, find their life work in the direction and the guidance of their operative fellows, should devote their skill, their experience and their combined effort to the guidance of this stream of change, to the training of this flowing tide, so that disastrous experiment may be avoided, undue haste controlled, and revolution and upheaval averted.

I have, in my time, seen efforts made to dam streams when in flood, such efforts have had and can but have one of two effects, either—as usually happens—the dam has been swept away, sometimes in the company of those who attempted to construct it, or the whole of the surrounding lands have been submerged by the rising waters. I hope that the employers of Great Britain will make no effort to dam the flood of class legislation with which we are threatened. I hope that they will recognise that it is a phase of the change which is occurring, and that they will seek to guide it into safe and stable channels.

I suggest that it is only a phase in the change which is taking place, because the class legislation now proceeding is the product of Trades Unionism. But Trades Unionism is suffering from the severe and repeated attacks of an enemy which has appeared on its flank, and of which the chief complaint against Unionism is, that it is and always has been a class movement; while true philosophy and the true service of humanity demand the elimination of all classes by means of legislation, which would make the State the unit and the nation the universal proprietor.

The complaint which Socialism makes against Trades Unionism must be acknowledged to be well founded, and whatever be the issue of the present struggle between the socialists and the non-socialists in the Societies, it seems certain that in the light of the facts which I have laid before you, the changes which we are witnessing will be permanent only in the sense that they will in the future form the basis for changes of a still more drastic character.

Whatever happens Engineers must still rule the world. Not only in great public works, as I have already said, but in every branch of life, mechanical skill in design as well as in execution will be demanded more and more, as machines become more and more widely employed for all purposes covered by human activity; indeed for all the purposes included in human existence, so that as it has been in the past, it will be in the future in even greater degree, the best men, the competent men of talent and of intellectual power who have a mind to work, will come to the front: while the mediocre and the idle will find their proper places in the rear ranks and on the back seats; for Emerson's dictum, however paradoxical his words may sound, is based upon experience and is absolutely true.

> "Space is ample east and west,
> But two cannot go abreast."

I have endeavoured to show that the changes of condition and of environment which we are witnessing are evolutionary and not revolutionary: that is to say, that they are but a part of a great forward movement which has been in progress for centuries, of which the rate of progression has undergone distinct acceleration during the last half century, and which has affected every department of human existence and activity: and I feel assured that no observer who is able to co-ordinate the various phases of transformation—whether physical or metaphysical—

which have taken place within the memory of men still living will disagree with the proposition, even though amongst observers there may not be unanimity of judgment in respect of the deductions to be drawn therefrom.

In this connection the astonishing change in idea concerning the fundamental structure of creation—the atoms of matter which, but a comparatively short time ago, were regarded as immutable and indivisible—which has followed upon the results attained by the physicists who have specially devoted themselves to the investigation of the phenomena connected with radio-activity may be noted in a brief and passing way: as in the words of Professor Rutherford (of McGill University), "a theory has been put forward in order to explain the phenomena of radio-activity, which regards the atoms of the radio-active elements as suffering spontaneous disintegration, and giving rise to a series of radio-active substances which differ in chemical properties from the parent element." On this theory, which is accepted by Professor Rutherford and other competent authorities, the radio-active bodies are demonstrating the trans-formability of elementary matter, and further, are demonstrating that stupendous stores of energy are latent in the radio-atoms themselves. What this may mean for the engineers of the future probably no man will be bold enough to predict; for who can say that these stores of latent energy may not one day be converted into stores of motive power.

In the meantime, I speak with some measure of confidence when I say, that it is possible that at no distant date, the engineering world will be startled by the revelation of a discovery relating to motive power, of such sort and of such far reaching consequence, that if I were permitted to describe it to you to-night, you would agree that it of itself may go far to establish the proposition which I have submitted to you this evening.

VOTE OF THANKS.

On the motion of Mr. ROBERT MATTHEWS, Past-President, seconded by Mr. THOMAS ASHBURY, Past-President, and supported respectively by Messrs. HENRY WEBB and JAMES VOSE, the thanks of the Meeting were unanimously accorded to the President for his address.

The President briefly responded, and the proceedings terminated.

ENGINEERING DEVELOPMENTS

IN A

SOCIAL AND INDUSTRIAL EVOLUTION.

READ SATURDAY, 10TH NOVEMBER, 1906,

BY

Mr. MATTHEW INGRAM,

MANCHESTER.

It would be commonplace to say, that industry and society are now both in a state of evolution, it may be more truthfully declared that "old things are passing away and behold *all* things *are* becoming new." The Social system known to and practised by our grandfathers has passed away for ever, and with it many of its degrading tyrannies, and the cruel hardships patiently borne by the toilers and moilers of the former industrial system of this country.

It is not, however, our intention to speak of the past, for "let the dead past bury its dead." Our present duty is to try to better the conditions, both industrial and social of the living; though we may say here, in parenthesis, the *past* is never dead, for life and progress never die; for a time they may appear to be dormant, and even retrogressing, but events always shew that such is but a temporary and evanescent episode in its history.

In glancing through the records of the proceedings of this Association since its inception, it has been found that the title headings of the subjects considered give no indication of any paper ever having been read, dealing with engineering in relation to either social or industrial evolution. Therefore,

we venture to think that a not unprofitable hour or so may be spent in an endeavour to find some common ground upon which we may unitedly deposit our little seeds of wisdom and if fertilized by experience, we may hope that they may one day fructify and grow, and that the ripe fruit may, in due time, be gathered, and so add to the sum total of our national prosperity and to the human happiness of the teeming millions of this our mighty empire.

As already stated, the subject of this paper is somewhat unusual for discussion by members of this Association, but we make no apology for its introduction on that score. We are all here interested in Engineering, in some of its many branches, and are concerned with the extension and elevation of these branches, this being indeed, the object for which the Association exists. We, therefore, feel fully confident we shall receive the sympathy and the support of the members in our endeavour to impart some interest, however small, on the very unusual subject of "Engineering developments in a Social and Industrial Evolution."

We think we shall agree, that all organic life has developed in form and structure from crude to complex, in obedience to an universal *natural law*. If this be true in the organic law of life, may we not reasonably assume that each succeeding generation of mankind will become more and more complex in its organisation; their wants will be more numerous, their standard of living will be higher, and their ideals will be more noble in the working out human destiny towards human happiness.

We will not however waste our time nor your patience, by quoting, or even enumerating authorities on the theory of evolution, as the question is understood by all who have eyes to see and a mind to grasp the changes that have taken place, even within the limits of their own lives and observations. We will proceed to try to discover some evidence at once which will

indicate the direction we may expect to see developments in Engineering in relation to a social and industrial evolution. We wish, however, to say here, in passing, that it is not our intention even to consider the past achievements in engineering, except in their relationship to the future, for the great achievements in engineering for the last fifty years have been so recently and so fully expounded by some of your most able and distinguished members during the Jubilee year of your Association.

Reformers, Politicians, and Philanthropists have tried, according to their lights, to improve the social and industrial condition of the mass of the working class population, and that too with some success, although the success had been out of all proportion to the efforts made and cost incurred; complete success will not, in our opinion, crown the efforts of any such agency, but will rather be obtained by the wise and intelligent organisation of industry, in which every unit will perform his or her part within such organisation, the benefits of which should be shared by all the units forming such a community.

When we find Reformers, Politicians, Philanthropists, and even Kings have failed to organise society, to whom shall we turn to bring about so very desirable a consummation? *The Engineer.*

When a great physical difficulty presents itself for solution, who is called in to solve and overcome it? *The Engineer.*

When nations become engaged in the deadly conflict of war, on whom do they rely to deal out destruction, death and defeat of their enemies? *The Engineer.* In short, it is the engineer on whom reliance is placed to ensure ultimate victory of arms.

When aerial navigation is accomplished and the North Pole be reached it will be by the skill of the engineer rather than the mere courage, intrepidity and enterprise of the traveller.

We need not multiply these facts, they are well known, and are patent to all who will run and read.

Who, then, is so well qualified as *the Engineer* to understand and direct the social and industrial evolution now going on, in which we should play some important part?

The true definition of an engineer, although differently explained by the dictionary, may be concisely defined as *organised common sense*, so that when organised common sense directs and controls the social and industrial affairs of this country, instead of political caucuses, commercial or financial expediency, then we may venture to hope, and may reasonably predict, that one of the earliest steps of advance will be to organise both society and industry in such a manner as will reflect the greatest benefit to the greatest numbers of such community, yet always keeping in view the greater interests of the nation or empire.

We venture to think that our present system of local self-government will require considerable modification and much amendment before we can ever obtain the best results from such a democratic form of government. A lesson in government by organisation would be learned if we were to copy some of the methods of certain great industrial undertakings, where the responsibility of defining the policy, the nature and the scope of the undertaking, is entrusted to a body of representatives of the capital invested therein; whilst the supreme authority in the carrying out of such policy is vested in the hands of a manager, whose powers of control and responsibility of management are subject to the representatives of the capital only.

Instances of the marvellous success of organisation are many and varied; two only need be here cited, one the Manchester Ship Canal Company, by whose organisation we obtain the advantage of having the whole world's surplus supplies dumped down, almost at our very doors, fresh and in

good condition, and in the most expeditious and economic manner; the other instance, being a great iron or steel works at which millions of pounds sterling have been obtained as profits by the proprietors, who deemed it cheap to pay their chief manager the large sum of twenty thousand pounds sterling per annum as a salary for his "knowledge" in directing the affairs of their huge undertaking to their advantage, but not necessarily to the welfare of the toilers and moilers, the creators of wealth, in which they enjoyed few of its advantages beyond their mere daily wages.

When we have society and industry organised on common-sense lines and upon a substantial basis, when the happiness and the prosperity of the whole community is aimed at, and not the undue aggrandisement of the few, we may then, surely expect some startling evidence of an industrial evolution in which engineering developments will play the chief parts.

Signs are not now even wanting in which we can discern evidence of a great awakening of the sleeping public, whose demand for cheaper and more expeditious means of locomotion and transit will have to be provided for, both on our highways and our canals, and he would be a bold man who would say we have in these reached but the very lowest rung of the ladder of progress.

When we have a Minister of Communication, responsible to the sovereign will of the people of this country, at the head of an organisation, with a proper and adequate staff of expert engineer assistants spread over duly defined districts, we may then expect that our canals will be so improved and extended, as to become a real service to the community, which at present they are far from being. And when our principal and secondary highways are designed and made to conduct traffic from one district to another in the most direct and the easiest manner, and

not in the most crooked and circuitous as at present, when in short, the roads are made for rapid wheel transit and not for mere pack-horses, then the distant village and hamlet will be within the limits of easy and rapid means of companionship as well as of social and commercial intercourse. When these and other means of intercommunication have been organised on commonsense lines for the advantage of the public, then we may hope, and indeed expect to see simple mobile means of both conveyance of goods and transit of people, which will revolutionise our present antiquated methods; and when cheap and a plentiful source of motive power can be obtained by utilizing the natural forces we already possess and now waste in a most shameful manner, and when "intelligent organisation" directs the affairs of a community we shall then, and not till then, have developments in engineering, in directions now not even dreamed of, by the most enthusiastic idealist of us all.

One of the first steps forward in the progress of a great engineering development must be a thorough overhauling of our social and economic systems, which should be organized in such a manner as to make it possible for all the adult units to contribute their share towards the common good of such community. To accomplish this very desirable end, a beginning should be made to reverse the present movement of population into towns and cities, where they are not required, and where as a matter of fact they often become a source of danger and a menace to society, whereas if they were retained in the country districts, their presence and labour would create wealth and prosperity for the whole nation.

Labour should be wedded to the soil, and not divorced from it as at present, for how can it be expected that a peasant having no hope, no ambition, no prospects beyond a present scanty pittance and a future certainty of a home in the workhouse and finally a pauper's grave, can give his best

either in labour or in intelligence, in the midst of such oppressive and appalling conditions?

In the future organization of the social and economic conditions of our teeming population, inducements must be provided to cause the superfluous labourers to get back to the land and so relieve the pressure of undue and undesirable competition of labour in towns, where it has already become a disadvantage to public morals.

In the organization of our village agricultural communities, means should be taken to ensure that an agricultural labourer in a village should have the same opportunity as a mechanic in a town to become an employer or owner; and if endowed with sufficient ambition, knowledge and abilty, to become a man of wealth and of light and leading. In short, by improving their social conditions and letting in the light of hope to their lives and the prospect of a reward for their labour and energy, it would spur them on to greater efforts in order to obtain more healthy and better social environments. Intelligent and intellectual intercourse between the different ranks and classes of communities would give an impetus to the creation and extension of small home or domestic industries scattered in villages and hamlets. These would provide remunerative labour for all who desired it, and just in proportion as the workers' means increased, so also would their wants, and in this way new industries would arise and thus still further increase the sum of engineering developments.

It will be asked how can this very desirable end be obtained?

We reply, by organisation on a commonsense basis.

A well known instance and also a contrast, may be cited as an illustration, and to point a moral.

An intelligent organisation enables the postal authorities of this country to collect and deliver letters to or from any portion of the United Kingdom, to every dwelling or business house

within the kingdom, for the cost of one penny; districts are so mapped out and arranged that one man alone serves a given district with celerity and almost unerring certainty as to time and place. But as a contrast, look at the *want* of an organisation in the collection and distribution of the morning and evening milk; this supplies us with an object lesson.

Whereas one postman will serve five hundred houses in a district, ten milk carts may often be seen in one short street all at the same moment, serving but one or more customer each in such street.

Surely it does not surpass the wit of man to organise the collection and distribution of milk, or of any other necessary articles, on a common sense basis to the advantage of the community at large.

When industries are organised on common sense lines the necessity of reducing the cost of production of all articles of domestic or general use and of developing small industries will be perceived, and, in this way, new and still more intelligent communities will be built up, and this in turn will largely improve the standard of life of the industrial masses, who can be further raised by providing them with intelligent and elevating culture, recreations, and amusements, after the completion of their daily business.

A new society would then arise whose aspirations would be towards a nobler ideal of life; and when the cultivation of the intellect will be made coincident with the development of the body, we may reasonably expect this evolution to bring forth a higher standard of population better fitted to instruct and govern our mighty empire upon which the sun never sets.

Reforms thus foreshadowed would inevitably lead to engineering developments, and in the reduction of cost of production of many articles in domestic or general use; machinery of an improved type would supersede and supplant the more antiquated

and uneconomical methods. It would be a question of brain force against brute force in the accomplishment of a given result, and machinery would supplant many of its irksome and laborious operations.

The evolution in the manner and methods of transit from the pack horse to motor carriage is marked by but a little more than a century's progress.

May we not reasonably expect a far greater acceleration of speed in the near future?

On whom shall we rely to organize speedy and economic transit of men and materials to the advantage and welfare of the community? Why, the *Engineer,* whose earliest effort will doubtless be to make the roads and highways suitable for rapid wheel transit, freed from the baneful clouds of dust and dirt, and with it the aftermath of discomfort, disease, and not unfrequently death.

On the accomplishment of this, we may expect to see the dawn of a new epoch in our industrial expansion and development. A new life will be opened out for our industrial and agricultural population, for it will be then possible to find them ample and remunerative employment in villages and hamlets where their social and domestic environments would be improved by associating with the more intelligent and skilful classes; further inducements would be present which would doubtless lead many of them to desert their sordid and insanitary surroundings for the healthy enjoyments of a more natural and higher life.

The greatest industry in this country is agriculture, and vast as it is in dimensions and value, it is the worst organised of all. If some of the energy, and much of the enterprise as is now, perforce, expended in industry to enable industry to keep its place in the competition of other nations were but employed in its organisation and development, a new and brighter era of

prosperity would shine upon that much neglected, yet essential, and most important industry.

Agriculture should be so improved and extended, even by intensified or forced production, or by any other means, as to make it feed the English people, as its extension would create new wants, provoke new desires for still further extensions, and thus new and extended industries would arise.

That there should be a re-marriage between agriculture and industry, is not only desirable but is essential if we are to keep our place in the progress of nations.

It is not so very long since when the marriage of agriculture and industry was both a happy and a prosperous union. At that time villages were the seats of a variety of industries, and the artizan did not entirely abandon agriculture; at that time, many of the towns were nothing less than industrial villages, for it was the rural manufacturer who really supplied the wants of the million, just as he does to-day in Russia and also to some extent in Germany and France and other parts of the Continent.

Land, it is said, is the source of all wealth. How this wealth is wasted for want of a commonsense organization is apparent to us all when we remember that in Great Britain we have nearly thirty-three million acres of cultivatable land, on which food is grown for only one-third part of the population.

In Great Britain we have 358 inhabitants per square mile, but produce home grown food for only 125 inhabitants per square mile; in other words, nearly three acres of the culturable land are required to grow food sufficient to feed *one person;* whilst Belgium with the densest population per acre in the whole world, not only grows food sufficient to feed the whole population of their country, but exports to *us* more than a millions worth of food stuff each year, and that too from land

which is far less fertile than the agricultural land of this country.

If we were to cultivate the soil of this country, even as well as it was cultivated forty or fifty years ago, twenty-four millions of people, instead of only seventeen millions, could live on home grown food, and the culture of which would give employment to an additional seven hundred and fifty thousand men, and would also give nearly three million wealthy home customers to the British manufacturers, who would be thus benefited thereby.

And if the cultivatable area of this country were cultivated as the soil is cultivated on the average in Belgium, we would have home grown food for at least thirty-seven million inhabitants, and further, if the population of this country came to be doubled, as it most likely will be in the not distant future, all that would be required for producing the food for eighty million inhabitants would be to cultivate the soil as it is even now cultivated in *the best farms* of this country.

The day may not be far distant when we shall be compelled to look to our own resources to provide the food we now import. And we shall not be the worse for it if we profit by the lesson of self reliance on the resources at our own command.

The resources of science both in enlarging the circle of our production and in new discoveries are inexhaustible, and each new branch of activity calls into existence yet more new branches which should further increase the power of man over the forces of nature.

In the organisation of agricultural production there is a rich field for future operations, and the engineer will command the highest honours, and occupy the highest pedestal of fame who succeeds in its accomplishment, and he will be no less a benefactor who succeeds in the economic organisation of its sale from the producer and its distribution to the consumer,

which at present is to the disadvantage of both, whilst being a loss to the nation at large.

The advent of steam as a motive power made the extension of machinery a possibility. New industries sprang up on every side and old ones were enlarged and extended, and as competition became severe manufacturers organised and remodelled their business, which had to be conducted on a large scale, to meet both home and foreign competition. And so it came about that industry became organised on what we know as the factory system, and the population following the demand for labour founded our industrial towns and cities, which, now by common consent, is considered desirable to decentralise in some way, so as to relieve the congestion of population, and to improve public health and morals.

The evolution through which society and industry is now passing points to the reversal of the process of half a century ago, and as science has enabled us to annihilate time and space by the telephone and telegraph, and the wide extension of power by electricity, gas and other forces, the concentration of industry in congested districts is neither necessary nor desirable. Whilst, however, believing that for most, if not all the big heavy industries, the economic management of which must be conducted on a large scale to make it profitable, we have no hesitation in saying there are hundreds of small industries which could be done away from such congested districts quite as well and at the same time under more favourable social, moral and physical condition for those now engaged therein.

The extension of large factories created a number of small industries, as for instance, cotton mills created great demands for bobbins, rollers, reels, and many other articles which could be made just as well in a village as a town. Science has placed in our possession means of transmitting power with little regard to distance, so that machinery could be

utilized for a large number of small industries scattered in village and hamlet, supplementing the larger and more important farming industry, and so forming intellectual centres of society, where fresh minds would be brought to consider fresh problems, and, like a pebble dropped into the pond, their circle of influence would radiate to its extreme limit, and thus further extend engineering developments.

It is said that education is the anvil upon which nations forge their wealth; how important is it then that the means of acquiring the best possible education should be extended to those living away from the great centres of industry and learning, who are now handicapped by ignorance, caused not by their incapacity to acquire knowledge, but by the absence of any facilities to obtain it; *when* education is so extended, then engineering developments will proceed with renewed force, and the nation's wealth and prosperity will be increased thereby.

It was an egotist who said "the engineers are the salt of the earth," but if the definition we give as the meaning of the word "*organised common sense*," then we see no reason to question his egotism, but it imposes upon us a duty to prepare the less favoured people for the social and industrial evolution that is now silently yet surely passing before us.

Great economic, industrial and social forces sometimes flow as with a tidal wave over communities hardly conscious of that which is befalling them.

It is *The Engineer* who should foresee what the whirligig of time is bringing forth, and endeavour to shape men's minds, mould our institutions, and direct their actions in accordance with changes that are silently yet surely surrounding them.

Those of us who lay no claim to the priceless possession of "organised common sense" can however, each in his own humble way, contribute some mite to the common stock of human happiness, human progress and national prosperity, and

so leave to our sons and to their sons a nation, the industrial, physical, and social condition of which, being alike the envy and admiration of all other nations.

DISCUSSION.

The PRESIDENT (Mr. W. Henry Hunter) in inviting discussion, said he understood the expression of Mr. Ingram's views to be a plea for socialism, and socialism too, governed and controlled by a central authority. A minister of communications was suggested, that was to say, that a social system administered by a central government was advocated. The question was one of pressing importance, and whether it was liked or not, it was a present question, and had to be faced. Therefore, he welcomed the paper and thought it would give an opportunity of discussing the advantages and disadvantages of possible alternatives in their economic system in a more thoroughly communistic direction. Whether it was, in the first place, to the interest of the engineering trade, and in the second place to the interest of those whom the engineering trade served, that engineers should attempt to expedite or to retard the development which was certainly taking place, were questions which would, he hoped, lead to a good discussion.

Mr. W. E. STOREY joined in the discussion with some reluctance, because the remarks he had to make might be considered in the nature of criticism upon the choice of subject of the paper presented. The author stated that he had not seen in the list of subjects previously dealt with in the Association's proceedings, a paper on the same lines. This was not surprising. The Manchester Association of Engineers was an association of professional men, men engaged in the practice of

a very complex profession, who met for the purpose of comparing notes on professional subjects. These men were probably also members of some debating society where subjects of this class would be more fittingly discussed, but to the engineer as such the subject of Mr. Ingram's paper was of little interest.

Examining the paper itself he failed to find in it any special appeal to the engineer on his professional side. It was as a member of the community that the social aspects of the paper would appeal to or repel him. It was true Mr. Ingram thought it would be the engineer who would be turned to in every social emergency. Surely, however, they were taking rather too much upon themselves if they denied to other members of the community that share of brains, experience, and common sense which were native, he hoped, to most Englishmen, and necessary in the conduct of public affairs.

They were told that engineering was "organised common sense," but this did not fully describe the engineering profession, nor the qualifications of an engineer. Such a definition took no account of his most perfect scientific training, long continued practice and pertinacity, all of which went to build up the necessary qualifications of an engineer. It was not the function of an engineer to organise society; organisation was not the chief part of an engineer's duty, it was only incidental to his duties. He thought an engineer's chief function was to bring to the service of humanity the resources of the earth, and devise and construct the means to that end.

The author had alluded to the engineer as taking a leading part in the evolution of industry, and Mr. Storey believed that all would be in agreement on that point. The fact of mechanical production of most commodities was a patent fact, mechanical production would increase very largely in the future, and they would all hope that this would lighten the manual burden of the down-trodden members of the community.

The necessities of a growing population, as hinted in the President's inaugural address, might compel much greater attention to be paid to agriculture, and by that means the conditions of life in villages, and the remuneration of rural labourers would possibly be improved, and tend to send "back to the land" some of the town's surplus population. But agriculture would not always be the chief industry of this country. It was undoubted that England possessed pre-eminently the means of industrial production, it had a vast wealth of coal, and as that made the production of motor power an economic possibility, manufacturing industury was bound to absorb an ever increasing amount of labour, whilst agriculture would gravitate to those countries where it could be carried on under more favourable conditions and on a vaster scale than in this country. Of course, that would bring with it social changes which would be considerable and inevitable. Where he (Mr. Storey) differed from the author of the paper was in the expectation that the engineer would initiate and direct this social evolution. He was of opinion that the engineer would be present and visible in those things and would answer to the call of the necessity of the moment, but he did not think he would be found leading in the front rank. The strictly utilitarian methods of necessity adopted by engineers made it a matter of considerable doubt whether the community would be best served by placing in their hands the chief direction of social reform.

The further developments of engineering were bound to be relative to those of industry. That was a truism, but the author had not given a very wide idea of the direction he expected those developments would take. Mention was made of improved means of transit for men and materials, which would revolutionise the present antiquated methods. That would undoubtly offer a big field in the future and would call more and more for

the services of the engineer. That was one encouragement for them, and to be prepared and able to do good service should always be their aim.

Mr. WILLIAM INGHAM thought that the subject of the paper was scarcely a suitable one for discussion by their Association. It contained no novel engineering data, or experience which would be useful for reference in the records at any future time. The paper was more in the nature of an essay on socialism, such as might very appropriately have been read before a literary club and debating society, and, whatever might be their opinions as to the ultimate effect of the rapid advance which was undoubtedly taking place in the popular idea of collectivism, as evidenced by the industries which were now being carried on by municipal authorities, and by the State, he did not think the paper just read was in accord with the objects of this Association as laid down in Rule I of the Constitution.

This rule declared the objects of the Association to be "the bringing together of those engaged in the direction and superintendence of engineering works, for mutual improvement, assistance, etc., and *inter alia* for bringing under the notice of members any subject or invention which from its novelty, usefulness or otherwise, may be instructive or interesting."

Although he (Mr. Ingham) was in accord with the author of the paper in many of the views he had enunciated, he must emphatically repeat that he was directly at issue with those who thought the meetings of an engineering association should be devoted to the discussion of social or political questions, however important they might be to the community at large.

Mr. SAM BOSWELL said that there seemed to be a difference of opinion as to the suitability of the paper, but where there was such difference there was useful discussion.

The paper mentioned that man's ideals would be more noble in the working out human destiny towards human happiness. But was there going to be no human unhappiness on the other side?

The Author was too hard on the agricultural labourer and his employer in making the reference to a "pauper's grave." There were no more agricultural labourers (in proportion to their number) who died in the workhouse, than there were other labourers from the industrial centres. The cry was "back to the land," but who drove him off it? If they went back to the land, where was the work? and who was doing it except the engineer? What was the engineer's self binding reaper then doing in the field? Previously there were not sufficient Englishmen to do the harvest work: except in very isolated cases there was now no necessity for outside labour, although about twice the amount of harvest work was now done, because the self binder (one of the products of the engineer) did the work of twenty men. Of course, that went to cheapen food and was to the good of the human being generally, but still it was somewhat hard on the agriculturalist to rob him of his occupation and then say to him "back to the land."

According to the paper, in Great Britain there were 33 million acres of cultivatable land; did that include Derbyshire? because, although Derbyshire looked a nice agricultural district they could not grow corn there. Why was no mention made of the land in western America, where, without labour or manuring, three different crops were got off the land each year. But were they always going to get this? Not when they had the land for agricultural purposes as long as England had. It was not to the engineer to whom must be looked for the increased production in the land, but to the Chemist, who was the only man as far as was then known who could improve the land's productive capacity.

He did not agree with the author in assuming that the owner of land did not know anything. If the landowner had got land which would grow corn, and that paid him better than anything else, he would undoubtedly grow corn. Also if machinery continued to be made to do the work of the labourer, the labourer must come to the town to help to make the machines, and the engineer should be the last man to take up the cry "back to the land."

Personally, he was obliged to Mr. Ingram for his trouble in preparing the paper, but was disappointed that no reference was made to the unfair condition of carriage charges offered by the railway companies to the foreigner for food stuffs, machinery, and general merchandise, as compared with the charges the English farmer or manufacturer was called upon to pay. Better organised distribution of commodities was wanted, but very little indeed was possible so far as the delivery of household commodities were concerned, as each desired to say when and whence it should come with a free hand to re-arrange when required.

Mr. Frank Prout said that the comparison between the post-office system of delivery of letters, and the distribution of milk, was not quite fair. The post-office certainly represented the monopoly system, but in engineering and other trades the comparison did not hold good, as competition would largely disappear, and with it the endless ingenuity with which competition was developed.

Mr. Charles Gregory said the previous speakers had criticised the author but he was going to speak in favour of much that had been advanced in the paper. Although the author's subject was not purely an engineering question, it still affected engineers to some extent. Engineers had to choose between

controlling the present evolution, or being swept over by it. In all previous evolutions both ancient and modern, some one class of the community had suffered. All that had been said by the author was pure common sense, in his (Mr. Gregory's) opinion. It might be said that what had been put forward was so much socialism, but the question really was, "Are our resources being developed as they could and ought to be"? If an engineer had a tool in his shop, and plenty of work for it to do, but only worked it three hours out of every ten, they would think he was foolish in not getting the full capacity of it. And if there was land available, and also the labour necessary to it, but only a small proportion of each was developed, a common sense view to take of the matter was to organise a greater and better development.

If they could produce the food stuffs required by the nation let them do so, as it would benefit the engineer by the revival and extension of industries which were at present languishing. He agreed with Mr. Ingram that agriculture was, or ought to be, the greatest industry in England, and as the industry dealing with the growing of the people's food, it ought to receive consideration in preference to every other industry, the growing of food stuffs being a matter of the first consequence.

He was sorry that some of the other speakers were inclined to ridicule the pretentions of the author, as like him, he thought that the idea of the engineer being the best man to direct progress in the future social and industrial evolution had a great deal to be said in its favour.

The meaning of the word "king" was defined by Carlyle, as "able man," and, judged by the standard of their works engineers were "able men."

He saw no reason why engineers should not, as a class, show the same abilities in directing the organisation of society, that

they had shown in the organisation of their own and kindred industries.

There was no doubt, that now, engineering as a result of mechanical invention, was an industry that was growing, very largely at the expense of other industries. Mechanical appliances were in every direction rapidly supplanting physical and manual labour, and, therefore, it devolved upon the engineer to take into consideration all those phases of life and society which affected him and his industry. Therefore, the least they could do, was to give Mr. Ingram credit for meaning well.

Respecting the land question, as viewed from the point of how it affected engineers, he would like to call their attention to the extraordinary burden placed upon the engineering industry of this country by the present system of mining rents and royalties. For instance, they had the authority of an eminent ironmaster (Mr. Gourley, he believed it was) who was of the opinion, that these excessive royalties of themselves would so cripple the engineering industry, that in the face of foreign competition, they would become a serious menace to the future progress of engineering in this country.

Those were matters worthy of the engineer's consideration, and if such burdens were to be taken off, engineers must lend their aid to effect the removal.

Mr. Jas. Vose said in his opinion there was every reason why the paper should have been given. It ought not to be unusual that such subjects should form part of the training of engineers, as engineers should take as part of their duties the training and developing of men, and the handling of men, as well as the handling of machines. The most important machines engineers had to handle were the men under them or working with them. It had been mentioned that commercial men would attend to any organising which would be required, and that it was not

part of an engineer's duty to organise, but, in his opinion, the man who was comparatively speaking a purely professional engineer, as distinct from a commercial engineer, had been allowing himself to be exploited by not attending to that kind of business, and the commercial men had been using him, more or less, for their own ends, Therefore, he thought they—the professional engineers—should have the common sense to do a little study and practice of commercial usages themselves, as the commercial end was only another branch of engineering. And the study of social problems had another aspect, through ideas thus engendered, engineers created needs, and, as a matter of fact, they needed to create hitherto undreamt of wants in order to find themselves employment.

It had been remarked, and he agreed, that it would be good policy if a lesson in government by organisation was learned from the methods of certain great industrial undertakings, where the responsibility of defining the policy, the nature and scope of the undertaking, was entrusted to a body of the representatives of the capital invested therein. The knowledge of the policy to be adopted, however, should not be confined to the fewest number, but should be shared to as great an extent as was prudently possible, and even the humblest man should do his own share in advancing that policy and his own and the firm's interest.

As regards the redistribution of the population, when anything in that direction was attempted, a "hornet's nest" was immediately stirred up. But what could be done with the land? He thought the remark Sir Henry Campbell-Bannerman made a short time ago, to the effect that "the land of this country would in future be less a pleasure ground for the rich, and more a treasure ground for the nation," would sink into people's minds.

In respect to supplanting antiquated and uneconomical methods by machinery of an improved type, engineers themselves

had perhaps their share of blame to take for any apparent lack of immediately available brains on the part of employees. The industrious looking man had been taken for too long as representing the ideal and faithful workman, whereas the man who was apparently so lazy that he would not do any more work than he could help, had probably brought out most of the labour saving inventions.

In his experience of men engaged in agriculture he had seen men on farms and so on, handling amounts of money and stock, who, if they were men in a town handling the same amounts, would be considered smart, up-to-date, prosperous tradesmen. He could not explain how some farms had gone on at all where men could not even write their name and cast up accounts, but somehow managed to make a sort of living.

Again, far from it being outside the scope of the engineer to deal with the derelict land question, he considered it was well within his scope. He did not say it was desirable for a professional engineer to deal with everything, but everybody who attempted to place any industry on a better plane was in effect an engineer, although perhaps he had never been formally trained as one.

Mr. JOHN MORRIS said that the first few speakers' remarks conveyed the impression that there was a kind of apology necessary from Mr. Ingram for bringing this paper before the association. In his opinion, however, it required no apology. An engineer should be sufficiently intelligent to look outside his own immediate occupation. In was, in fact, the duty of every engineer to be a well read man, and he did not think a man had read well if he could not put his politics aside and take a broad and dispassionate view of a subject even though it might go so far as to touch the fringe of so called socialism.

He was sorry the paper had been so severely treated by some, as he, the speaker, believed that the questions raised by the author would have to be faced and the means of solution provided by the engineer.

Some people talked about the present as being the very best possible state of affairs that could exist, but was it? with the submerged tenth we have heard so much about, and the millions of people practically on the verge of starvation, crowded together in our large cities, surely some better means of placing them in touch with outside districts than exist at present were needed. To provide these means was essentially a question for the engineer. Did anybody dream of cutting a railway from Manchester to Liverpool until the engineer constructed his locomotive?

Some of the largest firms in Manchester had done what Mr. Ingram had advocated, and one member (now present) was building a large works in the country. When these works were completed it was to be hoped that some hold would be kept on the jerry builders and those who set out the land and not allow the case of Openshaw and similar districts round Manchester to be repeated.

When Whitworth's and other large firms built their works out at Openshaw the land and building speculators immediately came on the scene, with the result that thousands of houses were built in long streets, at right angles, in painfully monotonous rows, with disgusting sanitary accommodation, as though the inhabitants were not expected to have any sense of refinement. They were altogether too crowded and too small for health. They had less air capacity than many houses demolished as slums within the last 20 years off the old parts of Deansgate, and were themselves fast developing into slums. Of course, the land question was largely behind it all, and if anything was to be done to improve this state of things on a scale large

enough to be of any use, it will not have to be left to private individuals.

Personally, he was much obliged to Mr. Ingram for bringing his ideas before the association. These things will have to be dealt with. Progress will certainly be along these lines and as these problems come up for solution the engineer will be needed. Unfortunately, whenever progress is hinted at and which appears in the least degree to touch vested interests and old time usage, it is stigmatised with the word "socialism" and at once becomes nauseous.

THE PRESIDENT (Mr. W. Henry Hunter) said he had to confess himself somewhat disappointed in the discussion, although he had been deeply interested in the speeches made. As he had already said, for those engaged in the engineering profession, with its many branches, the question of the future was as between socialism and individualism, and he would explain what he meant by that. Taking the line they were all familiar with, he would consider the question of the construction of public works such as those hinted at in the paper. He might first remind them of the allusion by the author to the development of the interior canals of England. At the present time there was a very weighty and important body of puble men, held in high esteem amongst engineers, who were sitting as a royal commission for the purpose of considering this question of inland canals, but before saying anything about those canals, he wished to re-call their attention to the history and experience of the canal they knew best, viz:—the Manchester Ship Canal.

That canal was the product of individual enterprise, it was a great work which was initiated and carried through, as in the first place being likely to be of benefit to the great community which it was to serve, and in the second, as being likely to

return some reasonable interest to the persons who put their money into it. That was the expectation at the time of the inception of the project, and on that expectation eight millions of money were subscribed, the millions of money thus subscribed by individuals being by-and-bye supplemented by the money of the community represented by the Corporation. What had been the result? There was not anyone who would not admit that the Manchester Ship Canal had been the salvation of this district. He had himself made that statement in many different parts of the world, even in Liverpool and in London, in which places they were at one time apt to smile at mention of the Manchester Ship Canal. The assertion stood to-day as admitted in fact, and had no dissentient so far as this great community, this City of Manchester, and the districts and towns of which it was the centre were concerned, that the Ship Canal had done everything in the way of collective benefit which was expected from it, and had even done more than was expected. A governmental dignitory came down to Manchester not long ago in order to inspect the docks, and brought a friend with him, which friend informed him (Mr. Hunter) that he had just had a conversation with a merchant, well known in Manchester, who had told him that his firm had got forty thousand pounds in the ordinary shares of the canal, that they had never got a penny of dividend for it, that they had never sent a bale of goods through the canal, and yet that they considered, that that forty thousand pounds had returned a better investment to them than any other investment which they had made, in the way of reduction of rail tolls and charges upon their rail-borne goods. That was only one instance out of hundreds of the indirect advantage which had arisen out of the construction and working of the canal and which had led to the general acknowledgement that the canal had been an enormous benefit to the community, but up to the

present had not afforded one penny in direct return to the individuals who had put their money into it.

Now, with such a condition of things as that, what prospect was there of carrying out the great public works which were required in this country if the capital therefor was to be found by individual enterprise. If such work could not be carried out as a matter of individual enterprise, then the matter became one of socialistic enterprise, or whatever else it might be called; it was a question for the community, "socialism" being employed as a term to distinguish between the enterprise and the effort of individuals and the enterprise and effort of the community, and he had, therefore, hoped that the discussion would have turned on that most important point.

Taking the question of inland canals in England, a great development of these was possible. A recent incident would illustrate what he meant. Some little time ago a manufacturer in the Pottery district had orders in his works for some crates for London, and some for New York. The freight from his works to London was 36s. 7d. per ton. The crates for both places were in his warehouse together, the packer made a mistake, with the result that some of the crates which were intended for London were labelled for New York and sent there, where the mistake was found out and the crates were returned direct from New York to their destination in London. The freight he was charged for sending the crates from the Potteries to London, via New York, was 16s. 6d. per ton, and the lesson seemed to be that the cheapest way of sending Pottery goods to London, was via New York.

That was simply a question of railway freights, and showed what canals would do, they would cut down railway rates, and would put the British manufacturer into a better position to compete with his foreign friends, with competitors abroad. The canals would undoubtedly do that, but they would never

return any remunerative interest on the sum which was required to enlarge and complete them. That was a great problem, which they, as a community, for the benefit of the manufacturing interests, should consider. Was the minister of communications, who was suggested, for the purpose of considering and determining these questions, to decide that out of public money he would improve those communications, and thereby do great benefit to the section of the community engaged in manufacture, and do great harm to that section of the community who held railway shares? Those were the kind of questions to be faced, and the matter was so serious and important, that he had hoped there would have been an engineering discussion on the subject, a discussion as to the questions which suggested themselves from an engineering point of view, and, therefore, he differed respectfully from the views advanced by Mr Storey and by other speakers who followed him. He had pleasure in proposing a vote of thanks to Mr. Ingram for his interesting paper.

Mr. GEORGE SAXON, in seconding the vote of thanks to Mr. Ingram, said that in his opinion the contents of the paper were the sensible convictions, and the earnest opinions of the author, and what had been embodied in the paper was what our education on this question had been leading up to for some time. It would be well under the circumstances, and the probabilities of the future, to keep a very open mind on these matters. As regards socialism, he did not fear this, except in one direction, the only socialism he feared was "secular socialism," he heartily welcomed "christian socialism."

As to the "back to the land cry," he feared there would be no remedy for that until their political engineers had had a turn and reformed the land laws, and made it impossible to raise any hindrance to the full and free develepment of the land. At

the same time, he agreed with one of the speakers that the land itself would not bring a full solution of the problem, or realise the ideal reforms and expectations of some of their socialistic friends. Of course, socialism had very wide aspects and divisions, and there was no doubt that in the future they would have to have a more open mind in regard to its development. Still, he thought such discussions ought to be carried on in the association very cautiously, as it was quite possible to divert the real intention of the association if they were carried away by some of those social problems and questions, and ignored the due introduction of scientific and practical papers in connection with engineering.

The author's definition of an engineer was rather too wide, engineers could not claim to be the only ones possessed of "organised common sense," and those who called themselves engineers ought not to forget that, and to allow the possession of that privilege to other members of the community.

Mr. Hans Renold wished to heartily support the vote of thanks to Mr. Ingram, personally, he could not be too thankful to him for having brought the paper forward, and for the way in which the subject was treated, which was not common in the Manchester Association of Engineers. They were all too much bound up by cast iron, steel, bessemer steel, and concrete. Probably all had read "Nasmyth's Life," and knew the successful engineer he was, and had seen in the book how he sometimes allowed his fancy to run off cast iron and such like, and sometimes even to go into fairyland. Mr. Renold believed that to make a really good complete engineer, they should also allow their ideas to go a little bit into the future, and into fairyland occasionally.

He had been very pleased with the president's allusion to socialistic ideas and social individualism, as this question had

affected him in connection with a new works he was building. It was a question of whether he should spend four or five thousand pounds on plant for making his own electricity, or two or three thousand pounds on plant for making his own gas, or whether to get it from the community, viz:—the Corporation. The latter course was a little dearer, but he reasoned that it would be better for him to husband his engineering works upon chain-making and those things which other people could not do, and make use of what the community (the Corporation) could give him. He was certain that in this matter he had got a very much larger return.

The motion was carried with acclamation.

Mr. M. INGRAM expressed his thanks for the kindly reception given to his paper, which so materially differed from those usually discussed at this Association.

In replying to the criticisms, he said he proposed to reply to the speakers generally, rather than in detail. There were, however, some exceptions which he could not allow to pass without one or two observations thereon.

It was a source of complaint by Mr. W. E. Storey and Mr. William Ingham that the paper was not a subject suitable for this Association, and the latter thought it was not in accordance with the objects of the Association as laid down by Rule No. I of its constitution. If, however, he had carefully read the rule he would never have made such an unsupported statement.

According to the contention of these critics, this Association was constituted solely to consider and discuss purely scientific, technical and practical engineering questions, whilst questions of vital importance to the national welfare and prosperity, were entirely outside the sphere of practical usefulness, or of the engineer as such, with which proposition he was entirely in opposition.

He was pleased to note the amount of interest shewn by the members in the discussion, and especially so when compared to a very recent highly scientific paper brimful of engineering technicalities in which one would have expected his present critics would have revelled in their scientific and technical knowledge, which might have been to the advantage of the members not so well endowed as themselves; instead of which, their eloquent silence was disappointing to the members, and, by "Strangers within our gates" all the honours were taken.

Mr. Storey, whilst not entirely agreeing with the author of the paper as to the definition of an engineer, thought that "engineers chief functions were to bring to the service of humanity the resources of the earth and devise and construct means to that end." With that definition he was in entire sympathy, and was also glad to be in agreement with Mr. Storey in the hope that engineers would take a leading part in the evolution of industry.

In no part of his paper did he say that engineers would be turned to in every social emergency, but he did ask, who was so well qualified as engineers to direct and control the social and industrial evolution now going on in which they should play some important part? and as no others, more qualified, had even been suggested, he was justified in his contention that "organised common sense" was the essential quality to be relied upon.

It was said he was too hard on the agricultural labourer. He could not however plead guilty to that indictment, seeing the whole tenour of his paper made for the amelioration of the physical and social conditions of the rural industrial classes.

It was further said that "although Derbyshire looked a nice agricultural district they could not grow corn there." This statement exhibited a want of knowledge quite inexcusable to one, who on other subjects, and especially on steam boilers, was so well informed; he would perhaps be astonished to learn that

in the autumn of this year, he (the author) had seen harvested in Derbyshire, fields of wheat which produced 45 bushels per acre, whilst the average yield of wheat over the whole of England averaged but 28 bushels per acre.

It was organised commercial and manufacturing industry which induced the people to flock to our industrial centres in such numbers and their condition was now almost universally considered a menace and a danger to the well-being of the nation.

Organised "common sense" should now be tried, whilst there was yet time, in order to avert a disaster and to induce the people "to get back to the land," and to improve their social and intellectual conditions by providing employment in improved and intensified agriculture, and domestic industries scattered in villages and hamlets, and thus add to their welfare and the prosperity of the nation at large.

It was well said by one of the speakers that "Engineers had to choose between controlling the present evolution or being swept over by it."

All historical records point to the fact that the ablest of all nations and tribes were chosen as leaders of men, and experience in England had shewn that the engineer had a capacity to organise and direct mechanical industries which had not been excelled in the whole world; therefore common prudence, let alone common sense should be the guiding principle in the selection, otherwise political influence, class prejudice and class interest may become the dominant power, and collectivism may sweep away individualism for ever.

Whether that would or would not be to the advantage of this country it was not the purpose of the paper to discuss.

It had been shewn that railways and canals were being worked not to the best interests either of traders or the general community, also that royalties on minerals were a tax upon

industry, and therefore an injury to the nation's welfare. Agriculture was languishing, and the land under cultivation was a diminishing quantity, whilst the population was increasing, and the demand for home grown food stuffs was out of all proportion to the home supply.

It was said that poverty, which was mainly the result of social and industrial systems, was responsible for nearly one million of people in England being on the verge of starvation, whilst in England there were nearly eleven million acres of cultivatable land, which, "tickled with a spade would laugh abundance for all of them."

With an educated, well-fed, well-paid, and contented population, who would deny that the industries of this country would be able to hold their own against the competition of their rivals, if they were organised upon a common-sense basis? When, however, industrial enterprise extended into rural districts, and railway and canal freights were reduced, and their usefulness extended, highways made suitable for speedy mechanical traction, cheap motor power available in all suitable districts, we should then not merely hold our own, but outrival all competitors.

Here was a vast field of operations to be explored, which in his (Mr. Ingram's) judgement, could only be accomplished by engineers, who were well trained and experienced in the management of men, as well as able to overcome difficulties under sudden and unlooked for emergencies. These were their peculiar and singular qualifications, and justified him in his belief that the successful organisation of industry and society would be best accomplished by the engineer.

CONSTRUCTION OF CENTRIFUGAL PUMPS.

READ SATURDAY, DECEMBER 8TH, 1906,

BY

Mr. WILLIAM G. GASS,

BOLTON.

The credit of bringing the centrifugal pump on to a working basis is usually given to Appold, but the knowledge of the centrifugal action of water with a revolving wheel has always been known to every handler of the household mop, and the invention of that instrument probably goes back to years before history.

Long before Appold's time, however, the centrifugal fan was at work, a centrifugal pump pumping air, and there were other makers before him also of centrifugal pumps, for as far back as 1713, Papin, the celebrated French engineer, designed one, and others have been made, both in England and America.

Since then it has been developed and improved, both in design and construction, till it has become the successful machine it is to-day, capable of raising water, or any liquid which will flow freely, from the smallest height to heights of 800 feet and more. Not that the same pump is capable of this range, but modifications of the simple pump have made it capable of this great height, representing as it does a pressure on the square inch of approximately 400lbs. In capacity also the centrifugal pump can be made with just as great range, and up to thousands of cubic feet per minute.

In the development of centrifugal pumps a variety of types has been evolved, but in all cases the pump consists of an outer portion, which I shall always refer to as the casing, in which the inlet and outlet passages are formed, and which encloses a revolving wheel, impeller, fan, rotor, disc, runner, piston, or bucket (these being various names for it) but which I shall always refer to as the bucket. This bucket is carried on a shaft, on which is fixed the driving pulley, or to which the engine or motor is attached, and where the shaft enters the casing the joint is made with a stuffing box, the shaft being carried in suitable bearings.

In considering the different kinds I have divided them, for simplicity, into four general types, but these must be looked on as being general only, as there are numerous variations, all of which could not be considered, even if I knew every variation.

TYPE A.

The first type which we shall consider is that of Type A. You will find in Fig. 1 A, a cross-section, and in Fig. 2 A, an elevation with the bucket shown in dotted lines. This has a single inlet central to the casing and no expanding chamber,

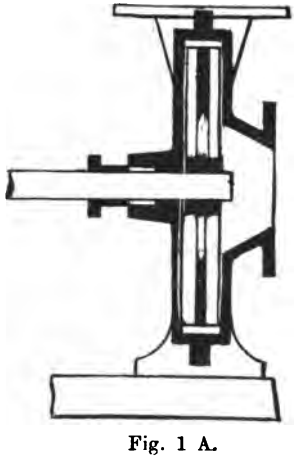

Fig. 1 A.

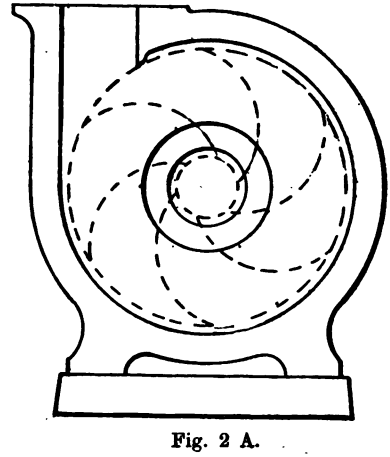

Fig. 2 A.

and is usually made only in the smaller sizes, say up to about 6 inches diameter of inlet and outlet, and the outlet as a rule is placed vertically as shown. Generally the casing is divided in the centre as shown, and the two halves bolted together; although it is sometimes made with a circular cover in front, and the outlet cast on to the main body of the casing.

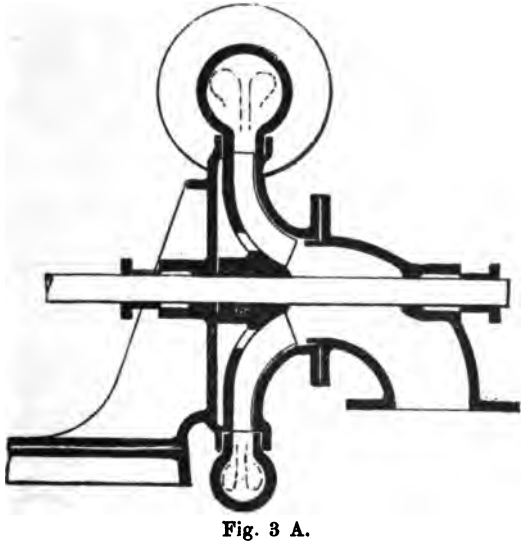

Fig. 3 A.

Fig. 3 A is another variation of this type, with an expanding chamber, and an elbow fitted to the inlet, which sometimes is used to form a support for the end of the shaft, and provided with a stuffing box and gland.

TYPE B.

In Type B we have another kind, and one of which there are a good number made, and which are made up to the largest sizes. Fig. 1 B is a cross-section, and Fig. 2 B a front elevation with the bucket shown in dotted lines. The inlet and outlet, though shown at right angles, are made at any angle with regard to one another, the casings being divided both on

the vertical centre line as in Fig. 1 A, also on the horizontal centre line, and in some cases with a sort of segment in the casing which allows the bucket and shaft to be lifted out.

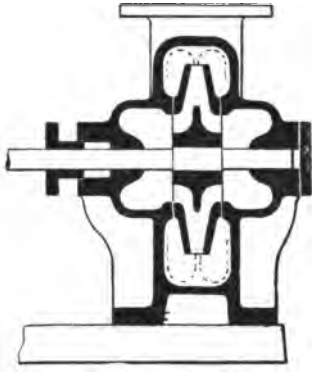

Fig. 1 B.

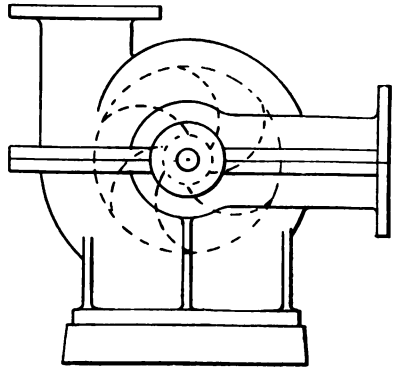

Fig. 2 B.

In this type the expanding chamber is provided by the eccentricity of the axis of the shaft with regard to the external diameter of the casing, and in the larger sizes by the additional widening of the body towards the outlet. The inlet is branched and the incoming water divided into two streams, giving what is known as the double inlet or balanced type; the idea being that the two streams of water entering from opposite sides balance themselves and remove any end thrust on the shaft.

TYPE C.

This is another form of the balanced or double inlet type, in which the expanding chamber is external to the diameter of the bucket and circular in section, but of increasing diameter, the space between the tip of the bucket arms and the expanding chamber being approximately parallel in section and circular in form.

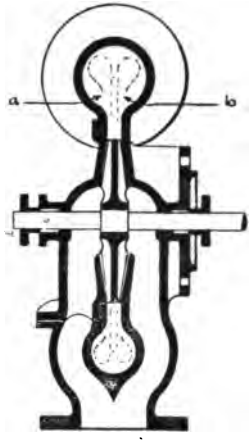

Fig. 1 C.

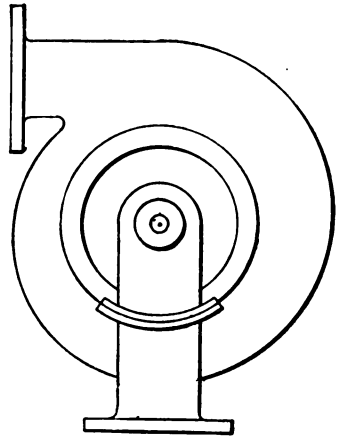

Fig. 2 C.

Fig. 1 C is a cross-section. Fig. 2 C an elevation.

TYPE D.

This is a single inlet, the expanding chamber developing external to the diameter of the bucket, but the continued development of which is carried out behind that part of the casing against which the bucket runs.

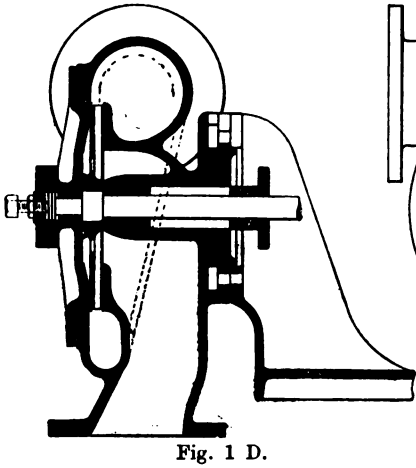

Fig. 1 D.

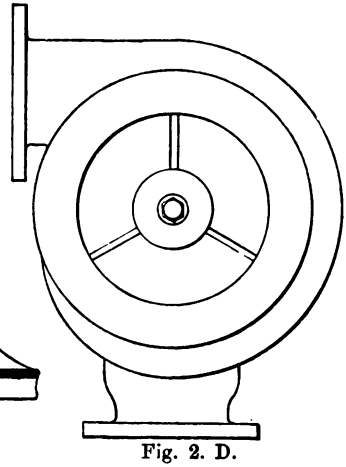

Fig. 2. D.

Fig. 1 D is a cross-section; Fig. 2 D elevation.

Fig. 3 D, Plate I. a photo. of a belt driven pump of this type.

Another variation of this type has the expanding chamber formed as in Fig 3 A.

The sketches of these four types show them all with the shaft horizontal and the buckets vertical, but they will any of them work equally well with the shaft vertical and the bucket horizontal, but they would then require some special form of bearing to carry the weight of the shaft, etc.

Numbers of pumps with vertical shafts have been and are made for special purposes, but they are usually but not always a modification of Type A, with an expanding chamber similar to Fig. 3 A. Also, in all the types they work equally well whatever the relative angle between the inlet and outlet.

Our next point for consideration is the bucket (which, as before explained, has a number of names), the portion of the pump which may be said to do all the work, and here we find they are resolved into two classes only, which are:

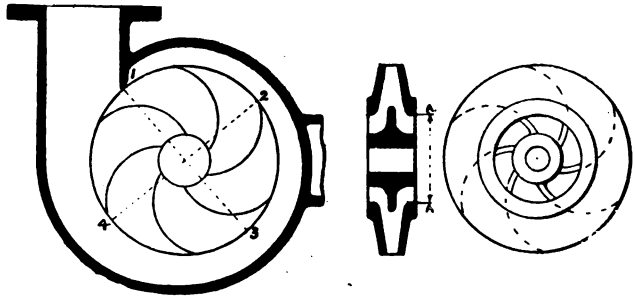

Fig. 5 B. Fig. 3 B. Fig. 4 B.

1st: The closed type, Figs. 3 B and 4 B;

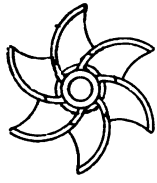

Fig. 3 C.

Fig. 4 C.

Fig. 5 C.

2nd: The open type, Figs. 3 C and 4 C.

These two are alike in principle, but differ in detail.

In the closed type the vanes are carried from the boss, but are covered in on either side, leaving a space in the centre on each side through which the water enters, and is confined between these covers until it leaves the bucket and is discharged into the casing; a dividing plate attached to the arms prevents the two streams coming directly in contact as they enter the bucket. This type of bucket is used in pumps of Type B, and is occasionally used in a modified form in both forms of Type A; in which case it has a single inlet only.

In the open type, which is generally used in pumps of Type C and D, the vanes are not enclosed, but run between the faces of the casing which encloses them, and when used in the double inlet pump has the dividing plate to prevent the entering streams striking each other. Both views show them of the double inlet type, but they are made of the single inlet as well.

In both types the vanes are generally curved and backward to the direction of rotation, although occasional makers use straight arms inclined backward in a similar manner; usually six in number, though four and eight are sometimes used, and occasionally, though very seldom, more than that number. The radius of curvature is given differently by different writers on the subject, but makers seem to each arrive at a form of curve which they find suits their requirements best; but as far as I know from examination of the different types which have come

under my observation there is no standard rule for curvature adopted by them all.

If the bucket were made exactly and mathematically correct we ought to have a different curve of vane for every change of speed and lift, but for manufacturing purposes it would involve so great a number of patterns as to be impracticable and a compromise has to be made. In the diagram, Fig. 7, is given a simple method of striking the curve of the vanes which I have found to work very well, both for open and closed buckets and up to large diameters, and which is in effective operation to lifts of 60ft. and over with best results. The method of striking it is as follows:—Divide the circle representing the diameter of the bucket into six or any number of arms desired—bisect each radii then using this bisected point as a centre and with a radius Bc = A B + $\frac{1}{6}$ of A B draw the curves which represent the working face of the vanes of the bucket. The back of each vane can be made to give a thickness suitable to the material of which the bucket is to be made. Different firms have different methods, but this is simple and easily understood by any workman who has to make the pattern, and is very effective.

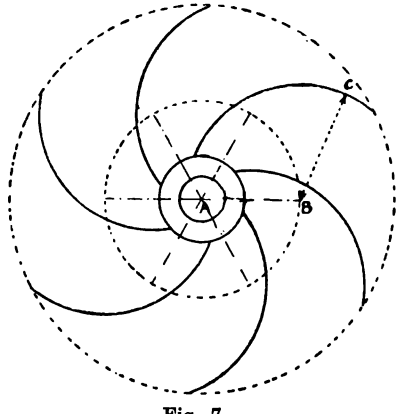

Fig. 7.

In comparing the two types of buckets it will be of advantage to consider for a moment the conditions which exist in a centrifugal pump when working. On referring to Fig. 1 B and 3 B, we will assume that the pump is lifting the water 5ft. and delivering it 5ft., and although not quite correct we will assume also that 2ft. head equals 1lb. pressure. The area of inlet is represented by the distance A to A, Fig. 3 B and 4 B, on both sides of the bucket, less the area of the boss. We shall find under the conditions assumed that over this area there is a negative pressure of 2½lbs. per square inch, which becomes before the water leaves the bucket a positive pressure of 2½lbs. per square inch, or what is the same, its equivalent velocity of discharge, so that between the discharge or outer circumference of the bucket and the inlet there is a difference in pressure of 5lbs., and there is the same difference between the inlet and outlet passages of the pump; it being also assumed that the velocity of rotation is exactly that required for the total head.

On referring to Fig. 1 B, you will see that in the case of the closed bucket all there is to keep the water in the casing which is under pressure from flowing back into the inlet passage is the accuracy of the fit between the comparatively narrow facings on the revolving bucket and corresponding fixed facings on the sides of the casings; and the point must here be borne in mind that the efficiency of a centrifugal pump is contributed to very considerably by the smallness of the space by which the water in the casing under pressure is prevented from returning to the passages where the pressure is negative. It also follows that the greater the pressure or head against which the pump is working and the greater the leakage, and consequently greater loss of efficiency.

The change from a negative pressure at the inlet to a positive pressure at the outlet of the bucket must take place in the bucket itself, and in the closed bucket this occurs between the

plates forming the sides of the bucket, and it would seem on that account to give it an advantage, and its advocates argue that there is less slip than in the open type.

Referring to Fig. 1 C and 4 C, the open bucket, there is no facing in this type, the joint being practically the whole width of the working face of the vane, and in addition the water moving radially makes it own joint. The conditions as to change of pressure, as described in the closed type, are exactly the same in the open type.

As an argument against the open bucket, is the statement that it is possible to make the closed bucket a better fit between the facings than the open one, and so, there must of necessity be more leakage in one case than the other; but this is not so, as they can both be made with the same clearance to begin with, and there is no more wear in one case than the other. As far as the centrifugal effort is concerned there is not any great difference between them, the slip in both being about the same.

In some cases, in the closed type– in order to reduce the leakage—one, two, or three facings are employed, with extra vanes on the outside to give a pressure between the facings: but additional facings are not a satisfactory solution of the difficulty. Another way has been to put loose rings in recesses in the casing, and keep them close up to the bucket by screws adjustable from outside.

The next point to consider is the casings and the movements which take place in them as the water passes from the bucket to the pump outlet.

In Type A, which is the cheapest type of pump made, and of which it may be safely said, hundreds, if not thousands, have been made, there is no attempt to reduce the velocity of the water leaving the bucket by means of an expanding chamber; and in many pumps the water emerges from the bucket only while passing the aperture of the outlet, so that, practically, the

delivery from the bucket is intermittent, each section delivering for about a quarter revolution, and doing nothing for the remainder. Of course the efficiency is comparatively low, and as it is only made in the smaller sizes and for low lifts, we need not waste any further time considering it. In Fig. 8 A, however, the conditions are more correctly allowed for, and it will be as economical as the other types; the flow of water from the bucket being similar to Type C to be considered later.

In Type B, as the expanding chamber is formed partly round the outer circumference and partly between the sides of the bucket and the casing, the distance from the circumference of the bucket to the casing is comparatively short, consequently the stream of water emerging from the bucket has to make a more or less sharp turn, as shown in dotted lines, Figs. 1 B, to pass to the space on each side of the bucket.

On referring to Fig. 5 B, which is a section showing a bucket and casing—in which numerals 1, 2, 3, 4 represent 4 sections of the delivery from the bucket—all the water leaving between 1 and 2 will form a stream that interferes with the delivery of 2 to 3, and the sum of these two will interfere with the free delivery from 3 to 4, and the total delivery of these will interfere with the delivery from 4 to 1. The general result of this is that there are two streams of water, one of which is moving more or less radially as it leaves the bucket, and the other moving circumferentially and formed of water previously delivered from the bucket; these two streams are practically moving at right angles, interfering with each other, and so absorbing a certain amount of energy.

If we turn to the action of the water entering the bucket it is necessary to divide the stream of water passing into the pump into two. Now to do this if you keep the sum of the areas of the two passages the same as the area of the one inlet passage, you increase the frictional area of the rubbing surfaces of the

water; or if you increase the area and reduce the velocity of flow you have to increase this velocity again as it enters the bucket or leaves the pump, causing a loss quite equal to the increased frictional surface of the two passages. In addition you have the effect of a sharp angle turn where the currents divide, together with the eddy losses set up by this division of the current; so that the losses which arise from the use of a divided inlet may very soon equal any advantage gained by the so-called balanced bucket.

There is also another defect in the casing of Type B, with the closed bucket. Where the casing is divided as shown in the sketch Fig. 2 B, and it also applies but not quite to the same extent when it is divided along the vertical line as in sketch Fig. 1 A, owing to the shape of the passages some of the joints have to a certain extent to be taken on trust, as it is only possible in the largest sizes to get at any bolt for these internal facings, there is occasionally considerable loss through leakage at this point.

We now come to Type C, in which the bucket is generally the open one, and the entry of the casing of the double inlet or balanced type. Referring to Fig. 1 C, the water in this case leaves the bucket and enters the expanding chamber in practically a circular plate of water of a width equal to the width of the periphery of the bucket. and moving radially or nearly so. As a rule this type of pump has the section of the expanding chamber circular and of increasing diameter with practically sharp corners or of very small radius, where the short approximately parallel passage known as the whirlpool chamber, from the pump bucket to the expanding chamber, joins it.

On Fig. 1 C, you will notice some dotted lines; these show the movement or the tendency of the movement of the water as it enters the expanding chamber. The natural tendency of the parallel moving sheet of water is to keep on in a straight line,

and as it loses its velocity it spreads out and follows the path shown in dotted lines. This movement is modified to a certain extent by the water already in the chamber and moving towards the discharge exactly as referred to before in Figure 3 B. Attention to this movement of the water was first drawn from traces of deposits having been found in some casings at points A and B, Fig. 1 C. I have only come across one pump in which this point of view was evidently taken, and this was in some large pumps made for Egypt in which the section of the expanding chamber was as shown in Fig. 5 C.

It will be as well here to say that the conclusions come to have not altogether been the result of experiment, but are arrived at as the result of observation of the different types under working conditions, and a careful examination of them when under repairs. There is no case which is more searching, or which more clearly shows how the flow of the liquid in the pump casing has been, than one which has been used for pumping water with a large amount of free acid, and the examination of a number both of these and of others used for all purposes and of every type referred to have been the basis of these conclusions.

In Type D, Figs. 1 D and 2 D, an attempt has been made to obviate some of these defects, and reduce the losses due to eddy.

In this type you will notice the expansion chamber is formed not in the centre of discharge of the bucket, but to one side of it; the bucket being of the single inlet open type, tapered to the periphery to keep the velocity of the water constant.

Referring to Fig. 1 D, you will see that as the water leaves the bucket it moves round the outside of the expanding chamber unbroken, and that which has previously been discharged, and is moving towards the outlet, has a free passage through the middle of the chamber. The general result of this is that the water leaves the pump with a spiral movement of very long pitch. By using the single inlet there is no loss due to dividing

the entering water, and a bearing is provided close to the bucket with another in the cover, both well protected from the water; while only one, and that the simplest form of joint, has to be broken to get at the bucket, and there is no difficulty whatever from end thrust with a properly designed bucket. The result of this type has been to get an increased efficiency of work, together with greater facility for examination.

In every type of pump the casing should be provided with a stop which fits the bucket as closely as possible at the point marked with an arrow, in Fig. 2 A, to cause the issuing water to move in one direction.

We may now summarise the points where losses of energy in centrifugal pumps arise.

1. Friction of the water in the passages.
2. Loss of energy where water enters the bucket. This is practically a right angle turn to the flow of the water, and as pumps usually go in line of pipes, impossible to get over.
3. Loss of energy when water leaves the bucket and enters the expanding chamber.
4. Leakage at joint of bucket with casing.
5. Slip of bucket.
6. Friction of shaft in glands and bearings.

These are losses in the pump itself, but there are other causes of loss which will be considered further on. Attempts have been made to increase the efficiency by making the entry from the passages to the bucket in the form of a spiral (Fig. 9), giving the entering water a movement in the same direction as the bucket, but it did not prove of any advantage after considerable use; the same effect has been aimed at with fixed vanes. There is another form in which screws, right and left hand, fixed on the shaft feed the water forward towards the bucket. In other cases fixed vanes have been put in the expanding chamber to guide the water. Although I have used them

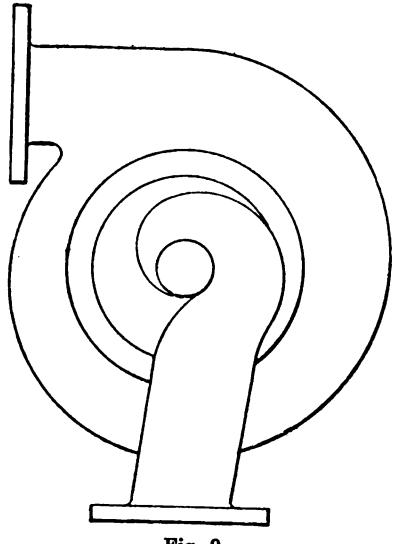

Fig. 9,

occasionally, they are not of great value in a single pump, except to act as stays for the two sides of the casing; they should be short as possible, and as few in number as will serve that purpose; and fish-back in section.

We now come to the mechanical part of the question, and this I shall only be able to consider somewhat briefly.

In the carrying of the pump casing off the bed plate this has gradually been resolved into two methods, one of which is to carry the casing off the bed plate on feet, as in Figs. A and B; or, what is practically the same thing, to cast the bottom portion of the casing into the bed plate. The other is to form a target end (Figs. C and D and photos) on the bed plate, and with a corresponding circular end on the pump casing; in this the casing overhangs the bed plate. This allows the casing to be turned completely round, and enables the pipe connections to be adjusted as required. It has many advantages over the fixed pump, for pumps up to, say, about

18in. diameter of inlet and outlet, but beyond that the weight of the casing becomes too great, and as feet have to be provided to carry the weight it has no advantage on the score of adaptability; but, even for larger sizes, I think it is the better method, particularly for Types C and D, occasionally for Type A, but it is not used for Type B.

All casings for dirty water should have good hand holes with removable covers to get at the insides of casings.

As to the question of proportions of the different parts, it is impossible to go into this in the limits of this paper; but, generally speaking, the proportions should be such that there is as little variation as possible in the speed of the moving water, and all the areas should be arranged with this object in view. There are cases where it is impossible to adhere to a fixed rule, and such cases can only be met by experience and knowledge of the special requirements, but a good deal more is needed than a purely mathematical acquaintance with the problem. The speed at which a pump runs is dependent on the diameter of the bucket, and the peripheral speed varies with the head required to be overcome.

There are many formulæ given for calculating this speed, some of which are very involved and others more or less correct, but the speed is affected to a certain extent by the general lines of the pump casing and shape and proportions of bucket.

The next point for consideration is the glands, which are usually of the ordinary type, one on the side of the casing from which the power is transmitted, and in some cases on the other side also. The packing gland is one of the troubles of a centrifugal pump, and the difficulties with it increase with the height of the lift, and the consequent increase of external over internal pressure; so that it seems like seeking trouble to put two where one would serve.

The bushes which form the bottom of the gland act as bearings, and these are often left to the water to lubricate, but they should be lubricated, if possible, and this is best done with solid grease forced in. In certain types this lubrication is not very practicable, but it should always be done, if possible, particularly in the larger sizes.

The glands also act as bearings, and for these means of lubrication should be provided, both oil and solid grease being used, the latter having my preference, as it is better for the packing than oil.

For packing the glands, cotton, (untwisted rope answers very well) soaked in tallow and blacklead, should be used; hemp being too harsh and liable to score the shaft, while asbestos is practically useless, either becoming as hard as iron, with no elasticity in it, or is washed out with the water.

I have heard of metallic packings being used, but have no experience of them, and should be doubtful of their efficiency as they would require more attention than in usually given to centrifugal pumps. Also a packing has been used consisting of a small centrifugal bucket fixed on the shaft working in a chamber and filled with water, but it cannot be used for either deep lifts or much head.

For pumps pumping sand, that is water in which is as much sand as the water will carry, clean water under pressure should be fed to the bushes of the gland to keep the sand out, ordinary lubrication being supplied to the gland as usual. Ample room should be provided in all cases on the shaft for withdrawal of the gland for repacking, without disturbing the bearings.

In belt and rope driven pumps the bearings are arranged as shown in the sketches.

Fig. 10. This is a faulty arrangement, as the pull of the belt has a tendency to wear the gland oval, with destruction of the packing, and consequent difficulty in keeping the joint tight.

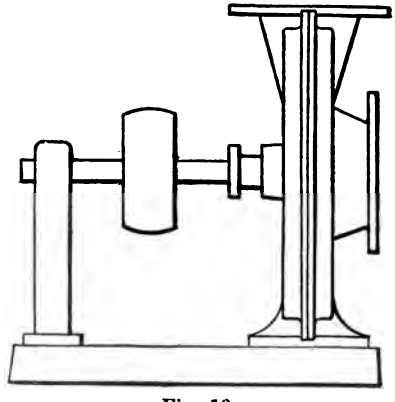

Fig. 10

Fig. 11, in which the pulley is overhung, is better than the previous one, but still has a tendency to cause the shaft to spring and affect the packing.

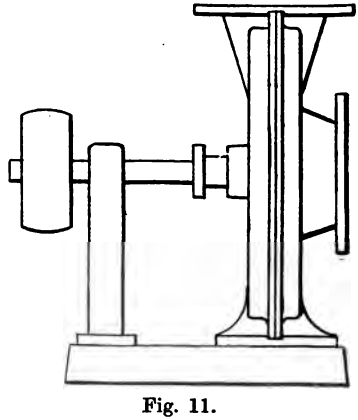

Fig. 11.

In Fig. 8 D, Plate I., in which a bearing is provided on each side of the pulley, is the best, as no pull comes on the glands.

When the pump is coupled direct to a motor a good many makers couple them up as shown (Fig. 18), and dispensing with any intermediate bearing. There are many objections to this, particularly if a flexible coupling is used; the best method is to

place a bearing just behind the couplings, as in Fig. 14, Plate I. It is more costly of course, but is a much better job.

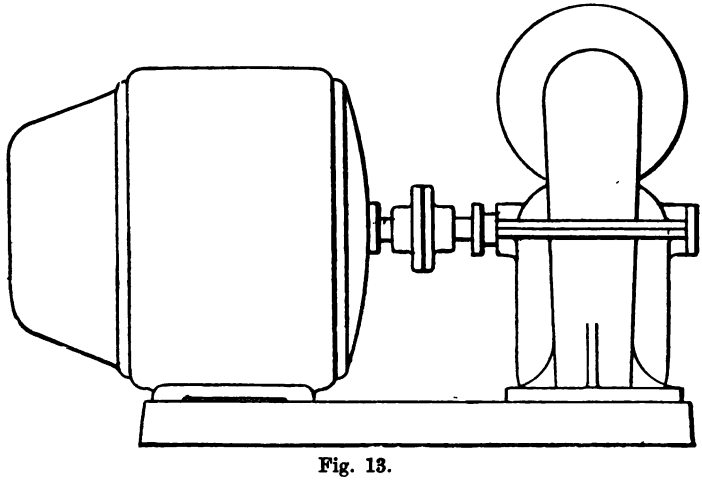

Fig. 13.

Where pumps are electrically driven there are many kinds of flexible couplings in use for connecting the motor to the pump spindle, and whatever type is used it should allow free driving even if the shafts do get a little out of line. As it is usually the armature of the motor which gives the trouble, it is of great convenience to have each half of the coupling also in halves for easy removal from the shaft. This is particularly applicable to places where a stoppage is serious, as in central station works.

The lubrication of the bearings also requires consideration. Where the pumps go in a hole, as they often do, and difficult of access when once fixed, the bearing if lubricated with solid grease should have long pipes and lubricators easily get-at-able or otherwise large oil cups. Self-oiling bearings are now being used but are liable to be neglected in out-of-the-way places. Where coupled up to motors the self-oiling bearings are, of course, general.

Fast and loose pulleys on the pump shaft are not very good, particularly if the pumps stand long periods with the belt running on the loose pulley. A much better arrangement is a loose pulley overhead, carried on a sleeve clear of the shaft, so that the belt stops when the pump is not in use. It is more costly, but saves the belts.

For driving pumps, belts and ropes are equally well adapted, but belts are in greater use because they enable a smaller driving pulley to be used than is possible with ropes, and though electric driving is more and more coming in, belts will continue in use, as there are places where a motor would soon be useless, independent of the cost.

For the larger sizes, and indeed for all sizes, steam engines are coupled direct. A centrifugal pump can be driven equally well by any type of engine, steam, gas, or oil, that will give the requisite speed.

Centrifugal pumps are speed pumps, and depend on a certain peripheral speed in the buckets, not only before they will deliver, but before they will deliver anything at all. It is surprising how often the suggestion is made, that a centrifugal pump would deliver half the amount if we were to run it at half the speed. Such, however, is not the case; a certain speed is necessary before the water will rise to the required height in the pipes, and a few more revolutions will make the delivery the full bore of the pipe; the delivery can be reduced within limits, but not by reducing the speed beyond the critical point.

One of the advantages of the centrifugal pump over others is its capacity for handling large amounts of water, the absence of valves, and its not being affected by dirt; by its capability of passing anything that is small enough to pass through the passages between the arms of the bucket.

But it must always be remembered that it is not a positive action pump, and the delivery can be stopped without

stopping the pump and without doing more than absorbing energy.

They are made of all kinds of material, generally of cast-iron, and a great many in brass or gun metal, cast-iron lead-lined, lead, ebonite, stone, earthenware, etc., and with buckets of cast-iron, steel, brass, or ebonite, with shafts of iron, steel or brass of various kinds.

As for the stuff they will pump, it is anything that will flow sufficiently easily to allow the centrifugal action of the bucket to take effect, and the presence of solid matter provided it is small enough to pass the bucket has no effect.

In fixing the position of a centrifugal pump with regard to the level of the inlet and the outlet, we have many considerations to meet; we have to remember that the height to which a pump will lift is that due to atmospheric action only, and that the greater the lift the greater the tendency to leakage either at the spindle packing, or at the joints in the pipes. Now if the means of driving the pump are not to be considered then by all means let the water run into the pump, and this is essential where hot liquids are pumped. You will then have no anxiety about leakage on the suction side (and a very small size of air leak will stop the pump) and the pump starts up the moment it has got its speed and if by any means the water fails the pump will start again when supplied.

In connection with cooling towers where the hot water from the condenser is pumped direct into the tower the water should always, if at all possible, flow into the pump, an overflow being arranged for, in case of stoppage of pump or other cause. In one case where the pump was belt driven and it was very difficult to gauge the speed to just keep up with the supply, the delivery was exactly met by means of an adjustable air valve on the suction to the pump. But running the water in is not

always practicable, and then we have to make other arrangements.

A centrifugal pump will not start work at all till the suction pipes are full and the casing is filled with water to a point above the top of the bucket. To accomplish this two things are done, one is either to supply a foot-valve or non-return valve at some point in the suction pipe and fill up with water before commencing, or to have a valve on the discharge of the pump, either automatic, or of the sluice valve order, and exhaust the air from the casing until the casing and pipes are filled; the pump will now be able to start work, the exhausting being done either by mechanical means or by a jet exhauster or similar contrivance. Where the lift is only very small, say 3 or 4 feet, a special arrangement of pipes will enable a foot-valve to be dispensed with.

This arrangement is shown in Fig. 15 and consists of a vertical leg which extends to a height above the water a little in excess of height of the pump casing, and having an inclined length connected to the pump. When once filled up this will

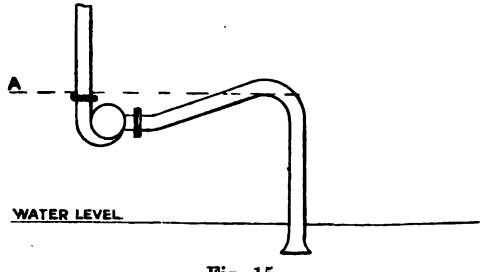

Fig. 15.

always remain filled to the top of the bend A keeping the pump casing full, and will enable it to start. The length of the inclined portion should be a little longer than the vertical leg, from the water level. Pumps of small size will start without foot valve for very small lift provided a certain amount of liquid

is left in the pump. In some cases with a lift of, say, 7 to 8ft., and where a large supply of priming water is available, the pump will start by turning in above the pump sufficient priming water after it has got running up to speed—but this is obviously only applicable to small sizes.

This brings us now to the question of the kind of foot valve which is best suited for the work.

When we consider that the loss of energy in the water coming through the foot valve even of the best type may equal a foot of head (and this is what should always be allowed) you will see that a bad type of valve may absorb considerably more energy than is desirable, as the speed of the water going through the valve may be anything up to 10ft. per second or even more, the area through the valve must not be choked; that is, it should have the full area of the pipes, and the stream of water should not be split up and should be moved out of the straight line as little as possible.

The perfect foot valve has not been made yet as far as my knowledge goes, but the best in my experience is that shown in Fig. 16. It is the ordinary hinge valve with rubber faces and a cover by which the inside can be readily examined. When

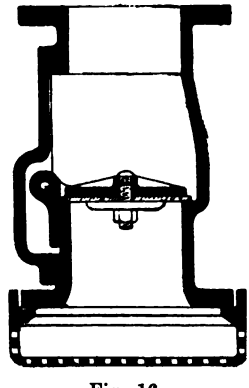

Fig. 16.

placed at the bottom of the pipes the entry should be bell-mouthed. For small sizes a valve with a rubber ball is as good as anything. Whatever type is used it will to a certain extent break the flow with consequent loss of energy.

As to the position of the foot valve, we have to determine that by what is being pumped. If it is clean, or approximately clean water, with not much solid matter that is likely to cause trouble, it can be placed directly in the water at the end or near the end of the pipe, the entrance protected by a suitable grating or not as may be considered desirable. But where the matter being pumped is dirty and offensive, as sewage, the foot

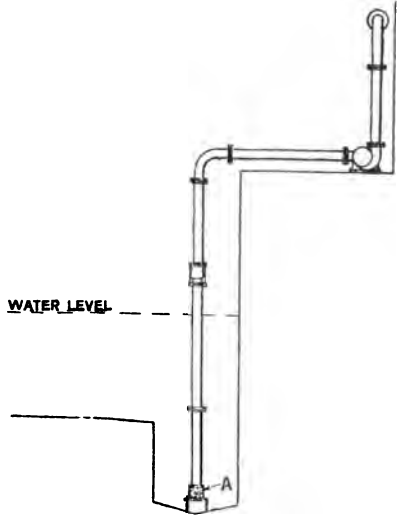

Fig. 17.

valve is better placed at a point higher up, as in Fig. 17, the grating A, Fig. 17, being below and easily raised for cleaning—the size of the holes in the grating being as large as the area through the bucket and altogether of considerably larger area than the pipe.

This removable grating is of great importance in sewage pumping, as it is astonishing what a sewage pump is sometimes asked to handle. In one case in my firm's experience, a pair of trousers had by some means been drawn into the pump, and in another case the inlet to the pipe, 12 inches in diameter, was completely blocked by cotton waste and cops, the pumps in this case pumping from sewers that drained an area containing several mills.

The foot valve is not used for large sizes, and for these the valve on the discharge with exhauster is the most desirable arrangement, but it has the defect that it is not self-starting and requires extra attention. Mechanical exhausters are occasionally used, driven from the pump shaft.

We now come to the question of pipes, and these and their correct construction and arrangement require the greatest care and attention if the centrifugal pump is to give its best effect, but which they do not by any means always get. They must be of full bore, as few bends as possible, and these of as large radius as practicable, and as smooth as they can be made. There should be no changes of area unless this is done by tapered pipes; square bends or T should not be used, and where the water enters the pipe the inlet should be bell mouthed so as to give an easy entrance for the water. The joints should be carefully made and care taken that the joints rings do not project inside so as to throttle the area of the pipe. It is very important on the suction side that means should be taken to thoroughly close all pin holes or porous parts which might exist in the metal of the pipes.

I give here the allowances which I have found in practical work to meet the resistance of the pipes, &c.

It does not exactly agree with some of the tables, but gives the requisite margin for contingencies which are always arising and which have to be allowed for.

It is expressed in terms of the head in feet, and is based on a speed of flow of 10 feet per second in the pipes; if the speed is less than that, then allowance can be made proportionately.

From 3in.	to 6in.	inclusive,	20ft.	of pipe requires	1ft. head.
,, 7in.	,, 12in.	,,	30ft.	,, ,,	1ft. ,,
,, 13in.	,, 24in.	,,	40ft.	,, ,,	1ft. ,,

Bends up to 24in. diameter.

When radius of bend equals	3	dia. of pipe,	requires	1ft.	head.
,, ,, ,, ,,	2	,, ,,	,,	1·25ft.	head.
,, ,, ,, ,,	1	,, ,,	,,	1·5ft.	,,
Foot valve or reflux valve.....			,,	1ft.	,,

You will see how the resistances mount up. If we take an example of a 10in. pump with 10ft. of vertical height of suction and 20ft. vertical height of delivery, with 250 feet of pipe with 3 bends and 1 foot valve.

Head due to vertical height	equals	30ft.
,, ,, ,, 250 ft. of pipe equals $\frac{250}{30}$	,,	8·3ft.
,, ,, ,, 3 bends	,,	3ft.
,, ,, ,, 1 foot valve	,,	1ft.
Total Head.....		42·3

The pump will be required to run at a speed to equal that vertical head to get a full delivery through the pipes; and the power will of course be required in proportion.

I have not said anything about deliveries of pumps because this varies with circumstances, but generally speaking if the conditions are satisfactory the delivery through the pipes should reach 9 to 10 feet per second, and under favourable conditions might even reach more, but this is about a correct speed, and the efficiency may vary from 50 to 75 per cent., according to circumstances and except in very small sizes.

Some extraordinary claims are occasionally made by pump makers as to what their pumps will deliver, but if the speed of the water is much in excess of 10ft. per second the power required to overcome the resistance of the pipes, etc., becomes relatively serious and should be avoided.

It may interest some of you to look at the photograph of pump, Fig. 18, Plate I. This, I believe, from information gathered from some of his old workmen, is a pump made like one that was claimed to be the first centrifugal pump made in Lancashire.

It was originally made by a man named James Hesford, of Bolton, about 1850, whose works were then in a cellar, and the photograph was taken from the last pump made from these old patterns, though long after his time. As to the accuracy of the claim I cannot of course be certain, but my informants believed it to be true.

In the compound or turbine pump we have the single centrifugal pump developed so as to obtain results which a single pump is not capable of, and results which at first sight would seem impossible to be obtained from a centrifugal pump at all. This has been accomplished by using two or more pumps working in series, that is with the delivery from the first passing to the second, the second to the third, and so on for as many series as are necessary for the head to be overcome.

Some writers have credited Sulzer, of Wintherthur, Switzerland, as being the first to use the compound pump, but as far as my researches go I cannot find any patents issued to him until a period long after the first English patent, and that is the earliest compound pump patent I have been able to find. A patent was granted to John Gwynne, No. 13,577, of 1851, and a claim is made "Of the application and use of two or more pumps combined to work on one line of shaft for the purpose herein described. A patent also was granted to Prof. Osborne Reynolds, of Manchester, and is No. 724, of 1875, and the claim referring to pumps reads as follows:—

"The arrangement and combination of two or more centrifugal pumps or fans in which the fluid after leaving the moving passages is received into the fixed passages, or passages moving

in the opposite direction, so formed as to deprive it of all velocity of whirl or give it a velocity of whirl in the opposite direction as herein described."

This is of course expired, but, in my opinion, it covers so completely all the arrangements of compound centrifugal pumps, that all that can be claimed by the later patentees is merely the mechanical construction of their particular pump, and not so very much of that.

But whatever Sulzer may have done in the way of putting his pump on the market, I think we may safely say that the idea originated in England.

It is quite true that on the Continent of Europe and in America they have gone in more for compound pumping plant than we have here, but all the larger makers of pumps here can now supply compound pumps equal to, if not better than, any of our foreign competitors; although our newspaper reporters do not believe it, this does not apply to pumping plants only.

In compound pumps the conditions set up are somewhat different to those of the single pump. The guide plates for guiding the water on to the next bucket so as to ensure its moving in the right direction are necessary, and these are fitted to all pumps, being arranged somewhat differently by each of the different makers.

You will notice in the sections of pumps given, that in Fig. 23, the closed bucket with single inlet is used, and is fitted with a balancing arrangement which is to balance the end thrust of successive buckets. Several makers have made their pumps with the buckets placed back to back, as in Fig. 21, to balance each other, but this necessitates more or less tortuous passages which should be avoided.

The compound pump may be roughly said to add a pressure for each successive stage equal to the pressure due to each stage if used as a single pump, that is if with a single bucket

pump you can get a pressure equivalent to 50 feet head, with two stages you would get 100, and with three stages you would get 150, and so on, and they are made now with 10 in the series, and up to very high lifts. The use of electric motors has given great impetus to the use of these high lift pumps and rendered possible their adoption where before they were impracticable, as driving these high lift pumps with either a belt or ropes is not at all a satisfactory way. With a compound pump also you can arrange it to deliver a large quantity at a reduced pressure, and deliver a small quantity at a higher where the conditions require it, by running the buckets in parallel or in series.

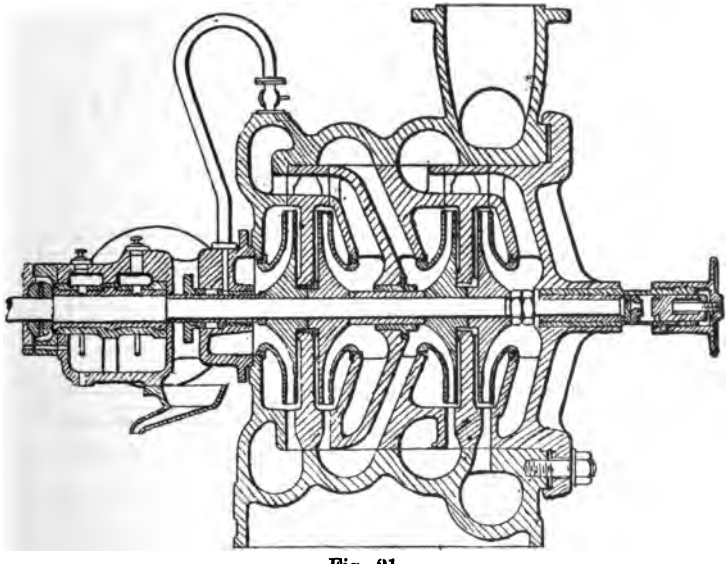

Fig. 21.

In the efficiency of the compound pump up to 75 and 80 per cent. is claimed for it, except in very small sizes, and the fact that the delivery is constant and not intermittent as with a reciprocating pump, the line of pipes can be made smaller for the same delivery, making a considerable saving in a long

range of pipes, but the speed of flow should be considerably less than for single pumps. Also by driving them with motors they can be arranged to pump in stages, one compound pump delivering to the next stage, the second one receiving the delivery under a slight pressure, and so on for considerable height, making them very suitable for deep mine pumping.

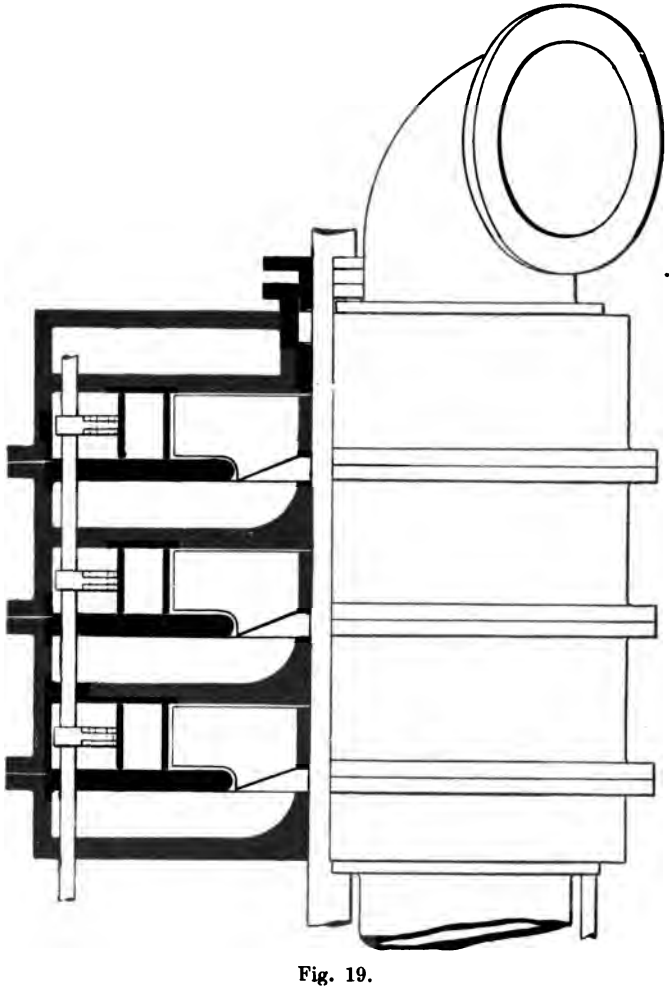

Fig. 19.

Referring to the different compound pump sketches :

Figs. 19 and 20 are Reynolds' pump of 1875 taken from the patent specification.

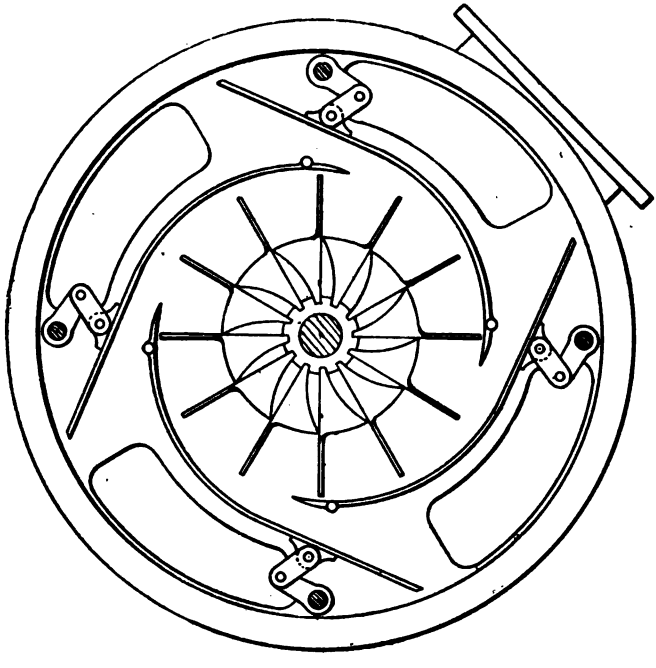

Fig. 20.

Figs. 21 and 22 are a Sulzer pump—4 stage—speed 890 revolutions per minute; diameter of bucket 20 inches; peripheral speed of bucket 77 feet per second; speed of flow in pipes 5·57 feet per second; pipes 8·7 inches diameter; head of water 424 feet.

Fig. 23 is a Mather and Platt pump—6 stage—speed 385 revolutions per minute; diameter of bucket 40 inches; peripheral speed of bucket 58·5 feet per second; speed of flow in pipes 5·05 feet per second; diameter of pipes 20 inches; head of water 300 feet.

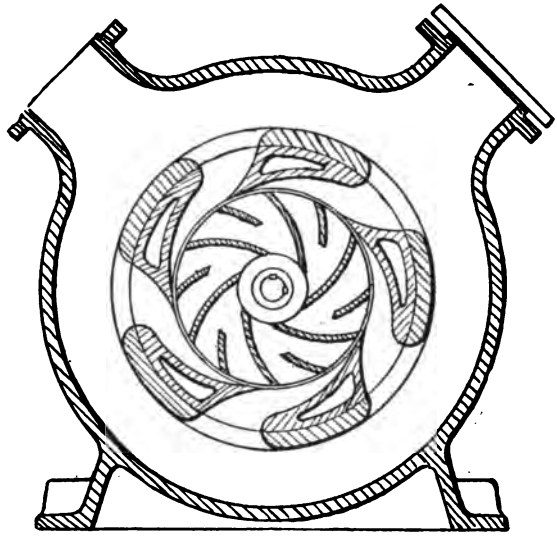

Fig. 22.

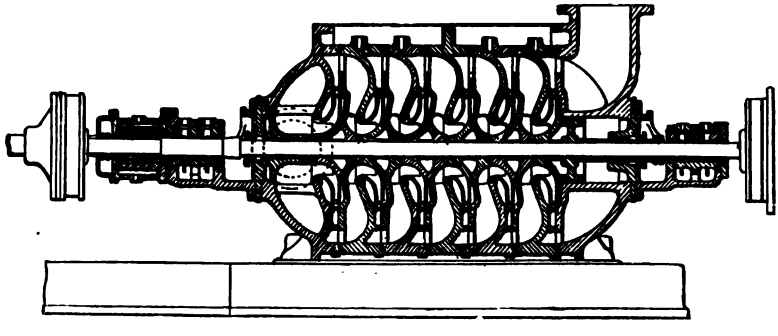

Fig. 23.

Figs. 24 and 25 are a pump using the open type bucket—4 stage—to run at 745 revolutions per minute against a head of 400 feet, the casing being made in halves along the horizontal axis to enable the interior to be examined and shaft removed, without disturbing the pipes.

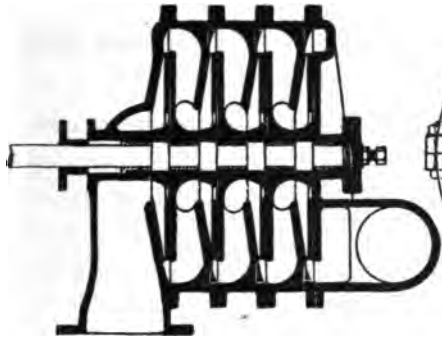

Fig. 24.

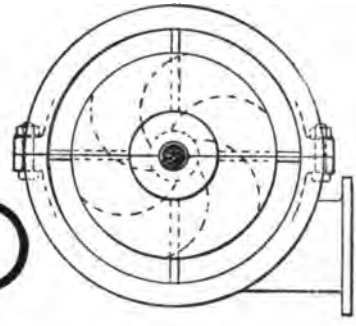

Fig. 25.

Figs. 21, 22, and 23 are reproduced by permission of "Engineering," from which the general particulars are obtained, and these two examples were taken as being fairly representative.

These different views will give you an idea of the general lines on which compound pumps are made, and there is no doubt that for deep pumping, and in fact for most kinds of pumping, the centrifugal pump is the one which is the cheapest and the simplest; it requires no air vessels, and has no valves to get out of order, and when once started only a minimun of attention.

I should like to draw your attention to a matter which, although it has nothing to do with the construction of pumps, has yet a serions effect on those working in connection with cooling towers. In all towns the amount of free acid in the atmosphere is considerable, and the continued falling of the water through the towers, meeting the upward air flow, has the effect of dissolving this acid, and the water used in the towers becomes so charged with the acid as to have a serious effect on any iron it may come in contact with. It would be advisable to use sufficient of an alkali in the water to neutralize this, and at all times the water used should be neutral, or better

still, with a slight alkaline reaction; the amount of air dissolved in the water renders a very dilute acid solution much more powerful in its action than it otherwise would be.

I hope I have made the different points of the pumps as clear as possible, but in the limit of a paper of this sort one can only be more or less general. There may be points in which my views do not coincide with those of other members, but I have only embodied views and considered those conditions which are the result of practical experience.

A great many attempts have been made by inventors to combine a screw and a centrifugal bucket together, but the results achieved by practically all of them can only have been equal to a single bucket with added complications and increased expense, so that there is no wonder they have not been successful; but still the idea keeps cropping up in all parts of the world.

Our President, in his address, said in effect, that to find food for the coming millions of people we should have to make the desert places blossom like the rose. To do that we shall have to supply them with water, and it is this water question which is going to be the salvation or otherwise of the whole matter, for it is believed from the researches both in Central Asia and other places, that the disappearance of some of these civilizations has been largely due to failure of the water supply, and to give the desert places water will require some gigantic pumping plants. But when this new motive power comes along which he prophesied the matter will very easily be managed, but it is hardly likely that such large engineering works can be carried out by individual enterprise, and the community will have to take the matter in hand.

It seems a long way from a centrifugal pump to a turbine steamer, but I am inclined to think that the high speed

propellors of these ships become too much like centrifugal pump buckets in their action when working, and that until this is corrected the best results will not be got from them.

DISCUSSION.

The PRESIDENT (Mr. W. Henry Hunter), in inviting discussion on the paper, wished to say a word as to his own personal interest in the question, and to express the hope from his own point of view, as well as from that of the reader of the paper, that there would be a thoroughly characteristic discussion. The session was begun by the reading of a paper which drew forth at the outset a considerable amount of what might be described as objurgation, notwithstanding which the paper elicited a flow of oratory and an outburst of poetic feeling that to him was of infinite cheer and great comfort. On the occasion of the reading of the second paper, they had just that which was asked for when the first paper was read, when so many members were pining for engineering details and engineering information, as in that second paper engineering details and technical information were supplied *ad libitum*, with the result that oratory ceased and the fountain of criticism was closed. He hoped that they were not going to have that in the present discussion.

He wished to mention how the question of centrifugal pumps affected him. The Manchester Ship Canal Company were now applying to Parliament for further powers, principally for power under which they could increase the inadequate supply of water in the Canal. They were proposing to instal, if they succeeded in obtaining the necessary powers, five centrifugal pumping stations, each of which would be of considerable size. It was proposed to pump at one station five million cubic feet in twenty-four hours—that was to say, sixteen to seventeen thousand

cubic feet a minute. He had, therefore, naturally looked to Mr. Gass's paper with the greatest possible interest. He had spoken with makers in different parts of the country on the question of the efficiency of centrifugal pumps, but their ideas on the point were very vague; and he had therefore looked to the paper for enlightenment, but found that the author had dismissed the matter in a single line by stating it might be 50 to 75 per cent.

He therefore hoped the discussion would deal with the question of the efficiency of centrifugal pumps.

He wished to call the attention of those who were working continually in questions relating to pumping, flow of water through pipes, etc., that there were on record the result of classical researches made by Professor J. J. Thompson nearly thirty years ago, which bore on these questions. Personally he had hardly ever known a mechanical or hydraulic engineer who was aware of their existence.

Mr. Joseph Corbett (Borough Engineer, Salford) said as a Borough Engineer, he had had experience with centrifugal pumps, and at present had one working which was about 170 IHP, and smaller ones down to 10 IHP. He wished to refer first to the President's query as to efficiency. He had a large pump by a very good maker, which on being tested carefully and repeatedly, gave an efficiency of only 46%, working with a lift of 30ft. Naturally he felt very dissatisfied, and was struck with the light way in which Mr. Gass mentioned an efficiency of 50 to 75%, as if it was quite ordinary. Mr. Gass also mentioned an efficiency of 75 to 80% for the compound pump. He (Mr. Corbett) did not understand how the efficiency could be increased by having some tortuous passages between one chamber and another; but perhaps those quotations of efficiencies were taken from makers' catalogues, and not from actual tests.

However, he felt grateful to Mr. Gass for the great amount of practical information which was given, and which he would no doubt make use of. He wished to challenge a few points on which he disagreed.

Mr. Gass had said that the peripheral speed of the pump bucket must vary with the lift. That was not so; it must vary with the speed due to gravity at that height, for it was a "throwing" pump, not a "thrusting" pump. For instance, it was known that if there was a heavy substance falling freely, it fell 16ft. in the first second, and at the end of one second its velocity was 32ft. per second. If it was required to throw it back again, it must be started at 32ft. per second to lift it that 16ft. The same rule applied in the centrifugal pump; the water had to be put to the speed of 32ft. per second if it was required to be lifted 16ft. That could be verified by reference to the figures the author had given in reference to the compound pump. He (Mr. Corbett) had calculated two examples. In the Sulzer pump, the peripheral speed of the bucket was 77ft. per second, and the gravity speed of each lift 82·4ft. per second. In the Mather and Platt pump the peripheral speed of the bucket was 58·5ft. per second, and the gravity speed of each lift was 56·8ft. per second. Generally speaking, and sufficiently near for practical purposes, the peripheral speed of the bucket had to be made equal to the gravity speed due to the height of the lift.

Mr. Gass had said that the water as it left the bucket moved out more or less radially, and that it had to turn almost a right angle to traverse circumferentially to the outlet. He disagreed with that statement, and also with another point which had been mentioned—viz., that the passages had to be made so that the speed of the water was even all through its course; a speed of 9 to 10ft. per second was mentiond. That would be correct for the main pipes, but, as would be noted from the examples he had quoted, the velocity of the water for high lifts had to be 30, 60,

or 100ft. per second, and, therefore, there could not be an even speed all through; the speed varied very much. He thought they would realise the sort of action very clearly by tracing what would be the movement of the water in the pump bucket.

Supposing this round plate (taken in hand) was a little pump bucket charged with water, with a height of delivery say 16ft.—of course, delivery and suction counted together for all calculations,—for that 16ft. delivery a peripheral speed of 32ft. per second was required. If the pump was made to revolve, and it was full of water, it was evident that the first motion of that water would be simply circular, and it would go round and round as a mere revolving drum of water, and the engine, if steam was turned on, would rapidly gain speed, as it would have nothing to do but revolve that drum of water, and would soon reach the critical speed of 32ft. per second. Then it would begin to deliver water, but this would already be whirling rapidly, and it would only deliver a very small portion at first, and would deliver tangentially, not radially.

He had found from comparison of several examples, that supposing the vanes of the disc contained 10 cub. ft. of water, this amount was not delivered per revolution in all cases; sometimes as much as 20ft. was obtained, but very often less than 10 cub. ft. Taking the larger delivery, supposing with a disc of 10 cub. ft. it delivered 20 cub. ft. of water per revolution, it was evident that the atom of water that started out into the disc from the top of the centre had to go half-way round a circle before it was delivered, and so it made a sort of volute curve and came out at the rim almost circumferentially, not almost radially.

As to the speed of the pump varying with the head, it was a curious fact, supposing the pump was set going charged with water and so on as already mentioned, when they got to a lift of

16ft. per second, the speed was 32ft per second, and it would begin to deliver; but supposing additional head was put on, with any ordinary pump at work it would slow down the engine, but with a centrifugal pump it would speed up the engine, because it would deliver less water; it would begin to simply whirl the water instead of delivering it, and so long as it whirled the water, the only resistance would be friction and the eddying resistance amongst the blades. As a matter of fact, when additional head was put upon the pump, it would automatically speed up to meet that increased demand. It delivered less water though it speeded higher, and that was a very useful compensating action in a centrifugal pump—viz., that it accommodated itself to its work.

Professor Rankine, going into the subject of the curves of the vanes scientifically, designed his blade with an S curve, the inlet end of the curve being almost radial, and the outlet end almost radial, and a double or reversed curve between the two. Most people, as Mr. Gass had pointed out, generally made one segmental curve. Others made a more flat blade, sometimes an actual radial blade, and sometimes canted back so as to chisel the water out from the centre. It seemed to him (Mr. Corbett) that almost a flat blade set at an angle in that way was really the truest form for the purpose.

He would have been glad to have heard of a number of experiments on that subject. It was possible, with modern facilities for manufacturing, and for testing, to make at a very moderate cost a dozen fans or discs of one diameter, and with different types of blades, which could be tried at many different speeds and lifts, and valuable deductions thus made.

The President had referred to the neglect of the theory by mechanical engineers. He (Mr. Corbett) and a friend had together endeavoured to trace out some of the elaborate mathematical theories given in text-books, but found there

was scarcely a single sound theory of the action of centrifugal pumps. They knew about the rudiments, but it was very desirable that some elaborate experiments should be made. So far as his experience went, the best result obtained for a centrifugal pump was 46 % efficiency, whereas with some of the pumps read about, up to 80 % was mentioned.

Mr. BRIGHT (visitor) said the question of the design of centrifugal pumps was a most valuable one. It involved considerations some of which were anything but simple. He did not quite agree with the author in his classification of pumps. What was meant by classification? He also could not understand why the pump shown in Fig. 3A, which had both a diffuser and volute, should be included in the same class as the pumps in Figs. 1A and 2A, which represented a very different class of pump having no diffuser.

The question of curvature of angles of the bucket vanes was of great importance, but it was dismissed with very slight notice. He would like to know whether the slight angle vane had any advantages over the radial vanes, or even the forward sloping vanes, or *vice versâ*. There were doubtless good reasons why in the majority of cases the slight angle was used, such as the more gradual change in direction which the water received as it passed through the wheel, and also the smaller velocity of whirl than could be obtained with radial vanes. Perhaps another and stronger reason for adopting a small tangential vane angle was that it was then possible, by reducing the speed, to reduce the flow of the pump at constant head to a much smaller quantity than that for which the pump was designed. With a rotary pump this could not be done, and the minimum discharge was that for which the pump was designed.

With radial or forward sloping blades, should the head against which the pump was working be reduced to some extent and the

pump run at practically constant speed, a high overload would be developed, with occasional disastrous consequences in the case of motor-driven pumps.

Regarding the hydraulic losses due to the wheel and casing, it was possible to calculate these with some degree of accuracy; the hydraulic efficiency could be obtained, and a general equation plotted for any particular pump. He would be glad if the author could give information as to the friction obtaining in the several parts of the pump. The statement in the paper regarding the friction losses in barrels was vague, and he thought it inadvisable to take such a rough approximation; it would be a better plan to take one or other of the various formulæ expressing these losses, and from it plot a chart from which the losses in any particular case could be read off.

He quite recognised the difficulty of embodying so many points in a single paper, and desired personally to thank the author for mentioning so many features of interest in the construction and working of centrifugal pumps, which class of pump for many purposes had advantages over pumps of the reciprocating type, notwithstanding their somewhat lower efficiencies. With careful design, the lower efficiencies of centrifugal pumps appeared to him capable of being considerably improved. Not the least of their advantages was that of cheapness, combined with compactness.

Mr. W. H. Roy stated that what he had intended to say had practically been mentioned by previous speakers, that was, that the author had said least about the point which, to most of them, was the main point of interest, viz., the efficiency of the centrifugal pump. So far as his experience went—and he had handled a considerable number of centrifugal pumps—he agreed with Mr. Corbett that the ordinary pump of commercial design

and the pump generally put upon the market in England, for moderate lifts of 30 to 40ft., had not an efficiency above 50%, and possibly in many cases it was below that.

In Fig. D there was illustrated an arrangement of casing which was not known to him; possibly it was a special arrangement of the author's. Had that casing any advantage over other arrangements which were better known?

Some figures were also given with regard to a 10in. pump with a certain head, and the author had estimated the total head. It would have been useful if Mr. Gass had taken that pump as the average size of pump for many purposes, and given the actual efficiency.

As regards the compound high-lift pump, makers of those undoubtedly claimed 75 to 80% efficiency, and he had no doubt that that efficiency had been obtained under favourable conditions. He had seen results of a test carried out at a maker's works of a compound pump working at 100ft. head, which gave an efficiency of 70%, and that was with one of the earliest pumps put in in this country. These published results were afterwards checked by an independent authority, at the place where the pump was working against 100ft. head, and the efficiency confirmed.

It seemed singular that it was not possible with lifts of 30 to 40ft. to obtain anything better than perhaps 50% efficiency.

Respecting the question of foot valves, the author had said that they were only used for small sizes. Mr. Roy thought that most people who had had foot valves would prefer not to use them for any sizes at all. Again, instead of having a strainer on the bottom of the pipe, and the foot valve placed higher up, a better method was to have an open bell-mouth on the pipe in the river or the well, and at the ground level near the pump, an arrangement of double strainers, and charge the pump by an exhauster.

A short reference was made by the author to a matter which indirectly arose in connection with centrifugal pumps, viz., the corrosion in pumps said to be produced by the water of cooling towers taking up acid from the air. He was rather surprised to find cooling towers made responsible in this connection. He had known of cases where the water in use in mill lodges had caused corrosion to the nails in cooling towers, and that had sometimes been attributed to mill owners filling up their lodges with sewage water. He did not say that that had actually taken place, but it was known in certain parts of Lancashire that some mill lodges gave off obnoxious odours, and it was therefore possible that in that direction there would be found direct cause for the corrosion in the pipes and in the pumps to which Mr. Gass had referred.

Mr. JAS. GUNTHER said that apparently the discussion was taking the line of the question of the efficiency of pumps. He would hesitate with an ordinary centrifugal pump, say 12in. bore, to offer more than 50 to 60% efficiency. Larger pumps would give a higher efficiency, but a high efficiency could not be expected from an ordinary centrifugal pump. In order to get a high efficiency it was absolutely necessary to construct the pump with guide blades, and that was one reason why the compound or turbine pump was giving such wonderful results in efficiency compared with the ordinary pump.

In a turbine pump the guide blades surrounded the pump disc, and the water being discharged from the disc had a certain velocity which was greatly reduced in the guide blades, and entered the surrounding chamber at a much slower velocity, so that there was considerably less friction in the chamber itself, and less disturbance of the water. If a pump, a low-lift pump, was properly constructed with guide blades and a proper chamber, as in a turbine pump, between 70 and 75% efficiency would be obtained without difficulty.

The curves of the vanes could be plotted and the exact path of the water determined. By varying the blade angle, the water could be made to flow in the one direction within great limits, and to practically follow any course it was wished in order to get any desired result.

As regards the curvature of the blades, if the disc blades were taken to be at an angle of 15° to the tangent at the outer circumference, the highest efficiency of the pump would obtained. With this angle, 1·3 $\sqrt{2gH}$ would be obtained as the circumferential velocity necessary to deliver the full quantity of water; that was, when raising against 30ft. the peripheral speed necessary to balance the water column was 44ft. per second, but the speed to deliver the water with the highest efficiency would be 1·3 this, equal together to about 57ft. per second. By making the blade angle larger, that speed would be reduced until at 90° the pump would deliver its full quantity of water at a speed exactly equal to that corresponding to the head; that was to say, a pump disc with a discharge angle of 90° would run at exactly the speed corresponding to the height of the lift—viz., $\sqrt{2gH}$, in order to deliver the full quantity of the water.

That, however, was not the outflowing speed of the water from the pump disc in relation to the disc itself; the actual velocity in the disc was only about half that, and by setting out a diagram of the velocities, exactly what took place could be ascertained. As the President had mentioned, all that had been worked out by Professor J. J. Thompson, and his was still one of the leading theories.

As regards the construction of the blades, Mr. Gass had no doubt taken this method for his own purpose. Each constructor generally used certain formulæ and fixed upon certain dimensions to suit his own requirements, and from that got his own graphic method. He took it that the construction given by Mr. Gass was a graphic method which he had evolved from the

construction of the pump itself. He (Mr. Gunther) had tried setting out the pump disc from this method, and found that it gave an angle of about 26°, which was about midway between a pump for the highest efficiency and one for the lowest speed; it gave a little slower speed of disc than the 15° which gave the best angle for high efficiency. That method of construction, so far as the discharge angle was concerned, was apparently perfectly correct, but he differed from the author regarding the vanes being taken to the centre of the boss, and thought that was not as it should be; the vanes should terminate at the central opening. He had tried to design the blades to the centre of the boss, but found he had then to give them a different curve there to that shown in the figure.

As regards high-lift pumps, as the compound type were quite a new development, he would have liked to have had fuller information as to what had actually been done. Wonderful results of efficiencies up to 85% were often mentioned, but things were apparently not always quite as they appeared, as he had heard rumours of 30 to 40%, or any efficiency but 85% being obtained. He was more conversant with the principles, so to speak, of water turbines than of pumps; still, the centrifugal pump, the compound or turbine pump, was nothing less than a water turbine reversed, and the same lines therefore applied. If only 80 or 82% could be got with the very best turbines, and that by using a single wheel, he did not see how 80 to 85% could be obtained with a small pump having three or four discs, and consequently increased frictional losses.

He would like to know whether there were any figures and data of actual tests which showed such high results.

One curious point in connection with a centrifugal pump which was probably not known, was in connection with the speed. If a pump was speeded for say 30ft. lift, and it was only being run on 15 or 20ft. lift, the pump would discharge

considerably more water and would take a great deal more power at that lower lift than at the higher. This was somewhat important in motor driving, especially if the lift was overstated and under actual working conditions it came much less, as there would be danger of overloading the motor, because the pump having a certain amount of water to deliver at the speed corresponding to the height of the lift would have to pump against a lower lift whilst running at the speed for the higher lift, and the quantity of water discharged at the lower lift would then be greater than the correct quantity that would be discharged at its proper lift. The result was the motor would be overloaded. That was an important point.

As regards the frictional resistances, he had checked several of those given in the paper, and thought them to be substantially correct, with the exception of the smaller sizes. He had calculated upon the basis of a 6in. pump, and the pipe loss came out very much greater. Pumps as a rule had not very long pipe lines, but Mr. Gass would find the resistances he had allowed in the case of the 3in. to the 6in. pipes rather too small. Roughly, in the case he (Mr. Gunther) took, at 9ft. per second the pipe loss came out 50% more. The formula he had taken was based on a mean of several different formulæ so as to elimiminate any errors. The reason he was rather strong on that point was that he had sometimes had to deal with long pipe lines where frictional resistances had to be taken into consideration very carefully, and he found the results obtained by his formula, and from actual observations when tested with pressure gauge, came out more than Mr. Gass had mentioned. The frictional resistances given for the larger pipes were approximately correct.

Mr. JOHN WATSON remarked that in his criticism Mr. Corbett made no mention of the centrifugal tendency set up in the

revolving water, and which to his mind must influence to some extent the efficiency of the centrifugal pump. They all knew that in a revolving body the co-efficient of centrifugal tendency varies directly as the square of the velocity, and inversely as the radius of the body, consequently, if two centrifugal pumps be considered, one of which is twice the diameter of the other, and both are run at the same peripheral velocity, the water, as it leaves the tips of the revolving buckets in the smaller pump, would possess much greater *vis viva* due to centrifugal tendency than it would in the larger pump. This it appeared to him must influence the pressure in the pump case, and be a factor in determining the duty the pump was capable of performing.

He wished to ask the author whether he had any knowledge or experience of a centrifugal pump having been used as an air pump to maintain the vacuum in the condenser of a steam engine. He asked the question not because he had any great faith in the efficiency of such a device, but because he remembered a well-known member of the Association proposing an arrangement of that kind some years ago, and he had often wondered if it had ever been tried, and if so, with what results.

A member wished to suggest that the Manchester Association of Engineers, in conjunction with the Manchester Technical School and any individual engineers who wished to obtain information, should carry out a series of tests to ascertain the efficiency of centrifugal pumps, and so remove the vagueness which existed on that point.

Mr. W. H. Cooke asked whether such tests as mentioned by the previous speaker were not already being carried out every day by Dr. Nicolson; there was installed at the Manchester Technical School what appeared to him to be a marvellous plant for dealing with the flow of liquids. He, therefore, did not

think there was any necessity for the members of the Manchester Association of Engineers to spend any money on such experiments as suggested.

As a matter of general interest in connection with the question of the flow of water, he mentioned that he had recently had a conversation with a machinery erector who had just returned from Italy, and who gave him a most interesting description of an installation he had assisted in fitting up. That installation embodied the first application of water for driving cotton machinery direct. In one room, in which were sixty-four ring frames of 400 spindles each, which would take roughly about 7 HP, each frame had fitted to it on the driving shaft a small turbine, and the water for these was brought down from the mountains in pipes. He was informed that the driving of the machines was something remarkable, and was an absolute revelation, the amount of variation being almost infinitesimal.

He thought that information would be interesting as a further development of the transmission of power.

Mr. CARLETON ANDERSON asked the reason why the spiral cone in the centrifugal pump had proved a failure; a number of pumps had been made on that theory, but were not a success, as the author probably knew. He understood there were one or two makers making turbine pumps for high lifts, whose aim was to make the water move right through the pump in the form of a spiral, and if this principle was entirely wrong, it would be very interesting to have some information as to the grounds on which its failure was obviously to be expected.

With regard to the speed variations, he had recently purchased a pump which the makers guaranteed would vary the volume of water discharged when working on speeds varying from 500 to 800 revolutions. It was a turbine pump for very low lifts (about 20ft. total), and what was required was a variation in

volume, which was to be obtained by means of variation in the speed of the pump. As a precautionary measure, there was a throttle valve on the discharge side of the pump, which would, at any rate, enable the volume of water to be varied, and would no doubt prove of assistance in adjusting the output to correspond with the best pressure to be got inside the pump at which it would give the best efficiency. The use of such a valve did not, as it might appear, decrease the efficiency of the pump.

He had noticed there was a tendency amongst makers to make turbine pumps, even for very large powers, to run at extremely high speeds; he himself had had offers of turbine pumps of 100 HP to run at speeds of from 1,000 to 1,450 revolutions to suit a three-phase motor. Such high speeds were very undesirable. Of course, it had been done, he believed, to get the greatest amount of work for the smallest possible cost, and, whilst that was a very good object, from particulars he had obtained of the actual running of such high-speed pumps, trouble had often been experienced with the bearings. That had led him to believe that those speeds were unnecessarily high, and he thought most engineers would be prepared to pay a little more money for a slower speed pump if they were assured that they would get value and increased reliability.

Mr. P. A. Mossay (visitor) stated that some time ago he was requested to lay out a line of electric motors, mostly of high speed, to drive centrifugal pumps, and he had then the pleasure of visiting and interviewing the most reputed makers at home and abroad, and had gathered a good amount of up-to-date information on the subject. The previous speakers had already taken up a few of the points he had wished to bring up in the discussion; none, however, had brought to notice that all the great advances in the construction of centrifugal pumps had been made in the last ten years. The principal cause of this was to be found in the

almost general tendency towards the use of high-speed rotary movers, such as steam turbines and electric motors, and also, it was largely due to the improved methods introduced by electrical engineers for the exact measurement of power, one result of which was seen in the possibility of designing accurately, and pre-determining the efficiencies of centrifugal pumps. Those possibilities were recognised at an early date by Messrs. Sulzer Brothers, of Winterthur, and it was undoubtedly due to their enterprise and great engineering ability that the centrifugal pump had been brought to its present state of perfection: others naturally had followed.

Mr. Gass, speaking of the design of the propellor vanes, did not in his opinion treat this important subject with the fulness it deserved. In small pumps, where the efficiency was of no consequence, a rule of thumb method might be satisfactory, but in larger apparatus he believed that each case should be studied carefully, bearing in mind the type of the drive.

One of the chief advantages of the backward curved blades in connection with low-lift pumps was that with them it was possible, by varying the speed of the pump, to vary the volume delivered over a wide range, which was very favourable in cases where a direct current motor was used for driving the pump. With radial or forward curved blades, this was not the case. For constant peripheral speed he could prove that with forward curved vanes the input increased very rapidly as soon as the volume exceeded a certain limit. Thus, should the head be reduced by any cause, there was considerable danger of the motor being overloaded. The reverse was the case with backward curved vanes.

Another point he wished to refer to was the efficiency of centrifugal pumps: Mr. Gass had fixed the efficiency of a single impeller pump at 50 to 75 %, and that of the compound pump at 75 to 80 %. This discrepancy was principally due to the author

having in view the low-lift pump without guide vanes; whereas, of necessity the compound pump had them. If the low-lift pump was provided with guide vanes a very high efficiency could be obtained. For instance, the low-lift pumps installed at the Niles Cataract, Egypt, by Messrs. Sulzer Brothers, which delivered 200 tons of water per minute against 70ft. head, were of the turbine type with guide vanes, and their efficiency was above 80%. He was also acquainted with another case where the efficiency came out at 84%. The design of the guide vane was of very great importance, and its bearing on the efficiency of the pumps should have called for more developments.

High-lift pumps were not necessarily of the multi-stage type, some had been built of the De Laval and Rateau steam turbine type, in which they had a single impeller rotating at very high speed, which in some cases was as much as 18,000 revolutions per minute. At such high speeds, however, suction became impossible, the water not being able to follow the rotating vanes and could not enter the impeller. That phenomenon, which was analogous to the cavitation of propellors, necessitated the use of an auxiliary pump to feed the main pump. The pumps were generally direct connected to the single stage turbine, the auxiliary pump being driven through gearing.

With a multi-stage steam turbine the speed could be reduced to 2,000 or 3,000 revolutions per minute, and direct coupling to a pump of one of the above types became possible without the use of an auxiliary pump. Although this arrangement appeared to be very complicated, it had a remarkably high efficiency, and was very well adapted for mining work where the space occupied by a steam turbine running at high speed was consequently very small, and thus the cost of installation and maintenance was considerably reduced.

The author had not called attention to a very important property of centrifugal pumps. It had generally been considered

that a pump which was designed for a certain set of conditions—viz., height of lift, quantity of water to be delivered, speed of motor, would not give satisfactory results under other conditions. That was not so. Provided those various conditions were altered in the right manner, the volume increased in proportion to the square root of the lift, the pump would give the same efficiency. It was remarkable from a design point of view, Professor Rateau has shown, that once a pump has been tested, characteristic curves can be traced from which the most advantageous speed and volume corresponding to a given head can be readily determined.

Such curves, once drawn, hold good for all pumps of the same proportions, whatever their size, a fact which was explainable by the theory of similar motions in hydraulics. By the use of such curves it could at once be settled whether a type already made could be used efficiently under other conditions than it was designed to satisfy.

Mr. Anderson had protested against the tendency to use very high-speed pumps on the ground that this was unsafe. He wished to challenge that opinion. The high speed in the pump was both beneficial to the efficiency, and to the cost of the motor and pump, as well as in reducing their dimensions. The polyphase electric motor was ideally suited to make a prime mover up to say 8,000 revolutions per minute, and up to 1,000 HP and above. The space occupied by such a set was very small, which was very important in all mining work. That those advantages were of great weight was borne out by the fact that the firm with which he (Mr. Mossay) was connected were building, amongst others, two three-phase motors, each 950 HP, for 1,500 revolutions per minute, to drive two Worthington high-lift centrifugal pumps for a large colliery in South Wales.

He also had before him some figures giving a comparison between two pumps at a colliery near Liége, Belgium. One was

a reciprocating pump delivering 1·03 tons of water per minute against 1,380ft. head, and this developed 96·5 HP. The other, a centrifugal pump, delivered 1·66 tons of water per minute against the same head, and developed 157 HP at 2,560 revolutions per minute. The total cost of the installations worked out at £14 per HP in the case of the reciprocating pump, and £4 per HP in the case of the centrifugal pump. The maintenance for the former was more, and everything pointed in favour of the very high-speed centrifugal pump.

The PRESIDENT (Mr. W. Henry Hunter) said that as the questions asked by the various speakers were so numerous, it was obvious that to do justice in replying to them, that Mr. Gass must occupy some considerable time. He would, therefore, ask Mr. Gass to simply deal generally with the questions at that time, and afterwards answer them in a written communication.

In proposing a vote of thanks to the author, he said that the preparation of the paper and the illustrations had involved a considerable amount of time and trouble, for which they felt greatly indebted.

Mr. THOMAS ASHBURY said he had great pleasure in seconding the vote of thanks to Mr. Gass for his paper, which was of great practical value, and one which they would appreciate. He was sure they were under a great obligation to him for bringing before the Manchester Association of Engineers in so complete a manner, the subject of the construction of centrifugal pumps; and he thought the discussion which had taken place would bring from Mr. Gass such replies as would considerably enhance the value of the paper.

Mr. R. M. NEILSON wrote that he had read the paper with much interest. The author had in a very clear manner described the different types of construction of centrifugal pumps, and

made interesting observations of their relative advantages and disadvantages.

Mr. Neilson added that at the Carville Power Station of the Newcastle-on-Tyne Electric Supply Company, centrifugal pumps had recently been installed for boiler feed purposes. Each of these pumps was driven by a De Laval steam turbine, and was of the compound type, having two impellers mounted in separate castings. The low-pressure impeller was driven by the second motion shaft of the turbine, while the high-pressure impeller was mounted direct on the turbine spindle. Each pump was constructed to deliver 200 gals. of water per minute against a pressure of 235lbs. per square inch. The turbine was supplied with steam at 200lbs. per square inch, and exhausted at atmospheric pressure through a coil in the feed tank.

Steam turbines are in many cases specially suitable for driving centrifugal pumps, on account of their high speeds of rotation. In the case of De Laval turbines, the extremely high rotary speed of the turbine wheel allows of very high delivery pressures being obtained with only two simple pumps arranged in series, the high-pressure impeller being mounted on the turbine spindle, as in the case of the boiler feed pumps he had just mentioned. Many such pumps were now in successful operation.

The American De Laval Steam Turbine Company had recently informed him that they were now building turbo-pumps in which a single impeller is employed mounted on the turbine spindle, and making 5,000 to 10,000 revolutions per minute, no gearing whatever being employed, and consequently a very compact and simple machine being produced, there being nothing more than a spindle with a single turbine wheel at one end and a small-diameter pump at the other, with a governor to control the speed. Such a pump had such distinct advantages that it promised to be extensively used where the conditions suited it.

In replying to the discussion Mr. Gass said, before answering the questions raised by the different speakers, may I express my personal gratification at the interest taken in the questions raised by the paper and express to those members who have taken part in the discussion my thanks for doing so. Not only to those who have expressed approval, but quite as much to those who have pointed out where I have failed to give information which might have been of more general value.

At the same time I must beg of you to remember that unfortunately for me my information is not universal, and, therefore, I am afraid I cannot answer as fully as I could like some of the questions raised by different speakers.

In replying therefore, I propose to take the speakers in the order in which they took part in the discussion, and will answer the questions, as far as I am able, in the order in which they arose.

Our President referred to my dismissing the important question of efficiency so shortly, but I would like to point out that what I kept in view as much as possible was the title of the paper. I was compelled in consequence to leave out a great many things I would like to have said owing to the paper becoming of too great length. As far as my information goes there is no real theory, nor have we absolute knowledge, of what takes place in a centrifugal pump when working, and consequently, in my opinion, the formulæ offered by many of the writers are based on more or less false premises, and that being the case are only approximately correct. These are so fully at the disposal of everybody that I did not think it advisable to re-produce them.

Now, to come to the question of efficiencies, we open up a subject in which we have much divergence of results.

Suppose we take a pump on a shop testing plant in which everything is done and everything made to secure the highest

results, the efficiency will be much higher than it is under working conditions where arrangements have to be subservient to the requirements of the situation, and where the efficiency may be much reduced by unskilful attention and worn parts.

I should say that the general run of pumps are not doing more than an average efficiency of 50%, and you get greater efficiency with large pumps than you do with small.

These remarks apply to the ordinary single lift centrifugal pump.

With regard to the efficiencies of the compound pump, I did not say they were getting the efficiencies given of 75 to 80%, but I said they claimed to be getting them, a distinction with a very great difference. If, therefore, in making your calculations you allow for a 50% efficiency you will be on the right side, except for very small pumps, the efficiency of which may be as low as 38%.

Mr. Corbett.—I think the efficiency mentioned by Mr. Corbett is certainly low.

In the question of the speed of the pump bucket, I think we both mean the same thing, only he has expressed the point in more scientific language; for if the speed of the bucket varies as the speed due to gravity at any particular head, the lift is against gravity, consequently the greater the resistance of gravity and the greater the equivalent lift, therefore the peripheral speed of the bucket varies as gravity or varies as the lift.

In the question of proportion of the various parts, I have found the best results have been got with a pump in which the proportion of the different parts are such as to give a constant sectional area at all points with a corresponding constant velocity of the water. Water is not compressible, and as a pump will not pump unless all air is expelled, it must follow that if you

have varying sectional areas you have varying velocities with corresponding losses due to eddies which arise from this cause.

The curve of the blade given was a graphic method of striking with very little trouble a form of blade which has given excellent results. A straight inclined backward blade gives nearly as good results also on medium lifts.

Mr. Bright.—The classification was based on the arrangement of the feed passages, and had no reference to the diffusers or volutes; it is not in any way arbitrary, but is, in my opinion, as good a way of classifying them as any.

The question of the angle of the vanes was one of much importance. The radial vane has less efficiency than the backward angle vane, but more than that of a forward angle, and though an angle at the tip of 15% is looked on as being correct, it is not certain that it is so, as the efficiency is largely affected by the general lines of the pump casings. With regard to the frictional losses in the pump casings, I treat the pump casing as a pipe with allowances for the bends.

Mr. Roy.—Type D is a type of pump which has developed from the manufacture of pumps of the other types referred to in the paper, and has given better results, and was mechanically better and more accessible.

The 10in. pump example was only given to show how rapidly resistances increased and had to be allowed for.

As to foot valves, I quite agree that they are not a thing to be used if they can be avoided; they were at all times undesirable but in many cases a necessary evil, and all that could be done was to make the best of them, as the charging of a pump with an exhauster was not always practicable. Where the pump was required to keep itself charged so as to be always ready for work a foot-valve was a necessity, unless the water flowed into the pump.

The suggestion as to the effect on the water by continually passing through the cooling tower seemed to me a very feasible cause of the corrosive action of some water; certainly some cooling tower waters gave a distinctly acid re-action, whatever the cause.

Mr. Gunther.—The 50% to 60% efficiency is what is usually obtained under favourable circumstances.

With regard to the vanes of the bucket running to the boss, this was rather deceptive on the diagram. In practice they are not fully carried to the boss, but die into it so as not to interfere with the flow.

I am much obliged for the correction with regard to pipe efficiencies for the smaller sizes, and shall embody it in my rules.

Mr. Watson.—I have no knowledge of a centrifugal pump being used in place of the air pump of a condenser, but I do not see any reason why it should not do all right if arranged in a proper manner, though I doubt if a very high vacuum could be obtained. The idea was patented over 50 years ago.

Mr. Carleton Anderson.—The screw pumps referred to were a combination of a more or less conical screw and an ordinary bucket, so many variations of which have been patented. In my opinion the reason of failure is due to the fact that the water traversing the screw is either moving slower than the pitch of the screw, or is endeavouring to move faster, either case absorbing power. Besides it is more complicated, and more liable to choke with refuse or chips.

The type of pump where the water travels in a spiral would be, I should think, similar to the Parson turbine, with fixed and revolving blades, but this is quite different from a combination of a screw and a bucket.

With regard to the high speed of rotation, it certainly enabled smaller pumps to be used and lighter shafts, but was bad for motors with continuous currents; the alternating current motor

was better for high speeds. Packing gland troubles were increased by higher speeds. Personally I prefer low or medium speeds to high ones.

Mr. Mossay.—The method of striking the arms given is hardly a rule of thumb method, and graphically gives in an easy manner a close approximation to a mathematically designed arm.

Efficiencies of 80 and 84% were claimed but very seldom achieved in actual working, and are efficiencies which make one a little sceptical about the method of reckoning. The figures he gave of the deep mine pumps were very valuable.

Mr. Neilson's communication was of much interest. It was certainly unusual to use centrifugal pumps for boiler feeding, but there was no reason why they should not be used for that purpose so long as they were capable of working against a sufficiently high pressure.

In conclusion, the preparation of the paper gave me much pleasure, and the necessity of looking up information for it has much increased my own knowledge of the subject, and I am much pleased at the excellence of the discussion. Will those later speakers who have raised (perhaps in another form) practically similar questions to those mentioned by earlier speakers, please take those replies as applying to them also.

In considering the question of arrangement of pumping plants, there is no doubt that centrifugal pumps give the least trouble, require the least foundation, require smaller houses, and, taking the capacity as the basis, are less than half the cost; while the maintenance charges are much smaller, and even where the efficiency is reckoned as 50% the result is very much in their favour, for the difference in capital charges is so great that it more than compensates for any small difference in efficiencies.

1 Plate follows illustrating this Paper.

TRIF

TRIFUGAL PUMPS.

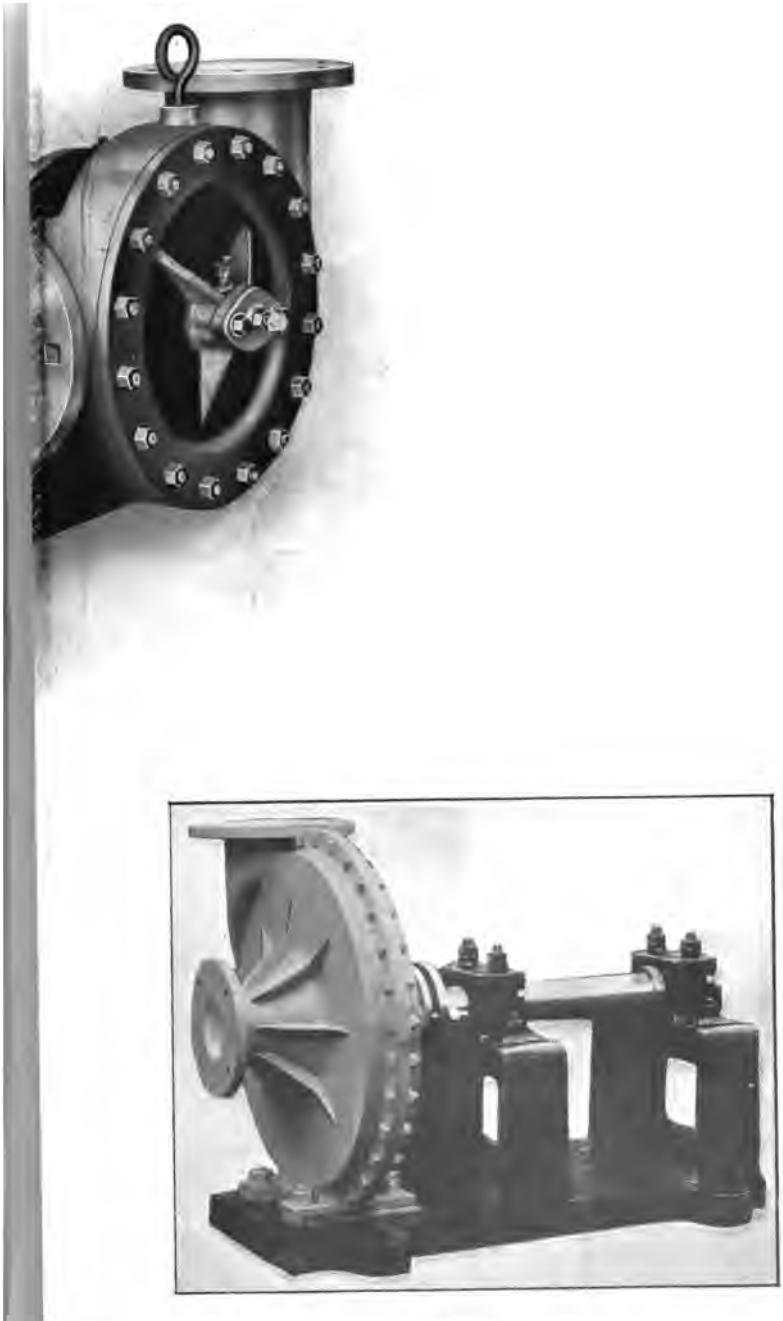

Fig. 18.

UNIV. OF MICH.

SPEED REGULATION OF ENGINES.

READ SATURDAY, 12TH JANUARY, 1907,

BY

Mr. G. JAMES WELLS, Wh.Sc.,

ASSOC.M.INST.C.E., M.I.MECH.E.

In order that the problem of speed regulation may be adequately treated, it is necessary that the varying relations between the external load and the working fluid be examined in detail, so that a thorough grasp of the problems involved may be obtained, and the designer enabled to discriminate between the possible and the impossible portions of the result desired.

The external load may be dealt with very briefly, as usually it is quite beyond the control of the engineer, and only a rough idea can be obtained of its characteristic variations. In dealing with a power station one has generally to be content with such information as its normal maximum value, and the greatest overload that the engine will have to deal with. Further, it is often stipulated that the whole normal load may be thrown off suddenly, or *vice versa*, the maximum load thrown on at once, and the engine must deal with the situation without its speed varying beyond certain limits.

For factory purposes the load is much steadier, the variations being much more moderate in amount, whilst the speed may vary through a somewhat larger range without trouble. A special "knock-off" gear is added to deal with exceptional cases, but this is a gear for emergencies.

From these considerations it is clear that the variations of the external load are irregular, and their occurrence cannot be

predicted under ordinary working conditions. They are "*non periodic.*"

The turning moment of all reciprocating engines must be irregular, in consequence of the effect of the angularity of the connecting rod, and the expansive use of the working fluid. The actual causes of variation of the turning moment can be divided into four sections for convenience of treatment.

(1) Variations of pressure in the cylinder due to the expansive use of steam.
(2) The effect of the angularity of the connecting rod.
(3) The effect of inertia of the reciprocating parts.
(4) The action of the governors, which by reducing the initial pressure, or altering the point of cut-off, changes the shape of the turning moment curve.

If these effects are briefly considered they will be recognised as having a "*periodic*" *character, i.e.*, the variations may be exactly reproduced in successive periods, and are thus quite unlike the fluctuations of the external load.

Causes (1) and (4) may be considered together, selecting the extreme cases of each for examination. The extremes are evidently the full and friction loads, for which the turning moments must be determined,

Assuming that about 8% of the full load is equal to the friction or light load of an engine, giving 1,500 IHP, with an initial steam pressure of 150lbs. at the engine, the total mean effective pressure being 30lbs. per square inch. Then the probable indicator cards for full load would be as shown in Fig. 1, whilst the friction load card would be something like that shown in Fig. 2, giving a mean effective pressure of about 3lbs.

Next by any of the well-known methods, the inertia pressures, and the effect of the connecting rod must be found and allowed for, so that the nett effective turning moment can

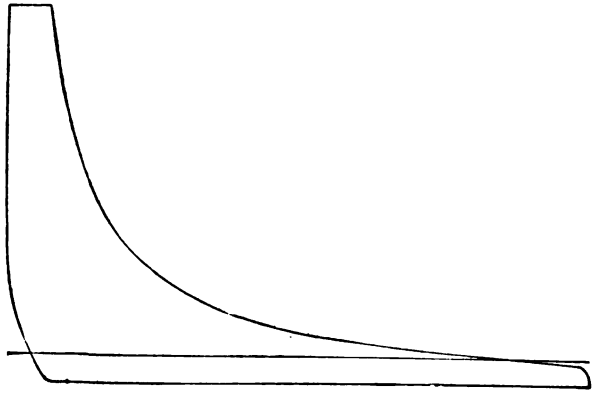

Fig. 1.

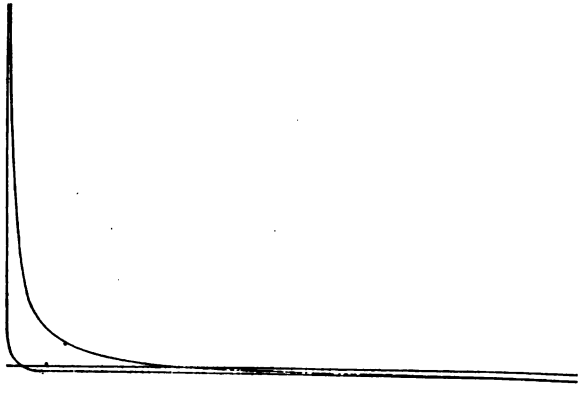

Fig. 2.

be plotted as a diagram for a complete period. For the full and light loads under consideration, Fig. 3 shows the final curves, which are drawn for a complete revolution, when the cycle of variations will be again repeated. It should be noticed that the external load is assumed to remain *constant* for the revolution under examination.

The dotted line drawn parallel to the base represents the mean ordinate, and is the mean moment of resistance due to the action of the full load. A B C D E is the curve of turning

moment for full load, and A F C H E the curve for light load.

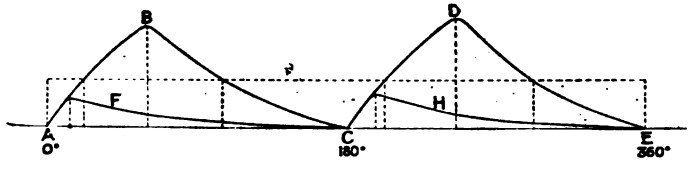

Fig. 3.

The orthodox method of computing the weight of the fly-wheel is to take the maximum excess or defect of area *between* the horizontal line and the turning moment curve, and find the weight necessary to prevent the speed exceeding the prescribed limits, when the energy represented by these areas is absorbed or withdrawn from the rotating wheel.

In order that the engine may be kept within the limits of speed it is necessary to do more than consider the maximum area of defect from the mean resistance, for it is obvious, that if when the engine is running at normal speed under full load, the whole load is *thrown* off, then the maximum area of excess energy is very much greater, which leads to a proportionately heavier wheel or the speed must of necessity rise beyond the prescribed limits. Similarly it is obvious that an engine running at normal speed without any external load, having the full load suddenly imposed, will have a much greater *area* to deal with than that considered in the orthodox way. This part of the subject will be referred to again at a later stage.

In practice it is customary to provide a wheel having a mass proportioned to the total amount of external work done per revolution, the ratio or factor employed being varied according to the nature of the external load, and the type of engine employed. The magnitude of this factor represents the *compromise* between unsteadiness and the commercial and practical objections to a very large wheel.

It is obvious that the *periodic* variations of speed can be kept within any prescribed limits by the use of a sufficient mass in the wheel, and that this limitation of fluctuation depends *entirely* upon the fly-wheel

Taking off, or adding to the external load, completely alters the balance between the mean turning effort and the external load, and it is necessary then to have some means of re-adjusting the balance by reducing or increasing the supply of the working fluid. This is the function of the governor, *i.e.*, the continual re-adjustment of the supply of energy to maintain the mean effort of the engine equal to the mean resistance.

The majority of engine governors are modifications of the original Watt pendulum governor, which is based upon the rotating pendulum. The simple "rotating pendulum" is shown in Fig. 4. The axis of rotation is necessarily vertical, and if we consider the ball to be rotating at a steady speed of N revolutions

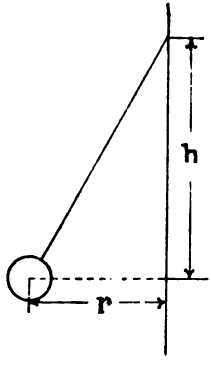

Fig. 4.

per minute the height of the cone described by the ball and its supporting string is

$$= \frac{35235}{N^2} \text{ ; inches,}$$

that is the height depends *absolutely* upon its angular velocity,

and for any other velocity the height varies inversely as the speed, the weight of the ball may be anything.

Practically except at very low speeds this form of governor is impossible because the height is too small, and there is also lack of sensitiveness. For any particular speed of rotation, there is some corresponding height, hence it is important to know the rate of change of height with any given rate of change of speed, for it is obvious that technical reasons demand that the change of height shall have a convenient value.

Let $\frac{1}{a}$ = the fraction of the mean speed equal to the difference between the mean speed and the maximum and minimum permissible. Then if $\triangle h$ = difference of height, and h = the height when running at mean speed, then it may be shown that

$$\frac{\triangle h}{h} = \frac{2}{a} \text{ very nearly,}$$

or the fluctuation of height is equal to twice the fluctuation in speed. Suppose that the variation of speed specified is 5%, then $\frac{1}{a} = \frac{1}{20}$ and the ratio

$$\frac{\triangle h}{h} = \frac{2}{20} = \frac{1}{10}$$

and if h = 10 inches the governor mechanism would have to be so arranged that a vertical rise of the walls of 1in. must suffice for the movement of the controlling gear through its whole range.

The "Porter" or loaded type of governor provides a means of increasing the height for a particular speed, and as a consequence the absolute variation of height required for the controlling gear is correspondingly increased. Such a loaded governor is shown in Fig. 5, and the height

$$= \left(\frac{w + \mathrm{W}}{w}\right) \frac{35{,}235}{\mathrm{N}^2} \text{ inches,}$$

where w = weight of each rotating ball, and W = weight of counterpoise or central load. Thus by making the ratio $\frac{W}{w}$ large the height is increased and the ratio $\frac{\triangle h}{h}$ can be made smaller, and $\frac{1}{a}$ reduced, that is, the *sensitiveness* may be increased very materially. By loading the governor its sensitiveness may be increased to any reasonable extent, but it can never become *isochronous*, for it is obvious that some alteration in height is unavoidable, and a governor to be isochronous must have the same height for all positions of the balls.

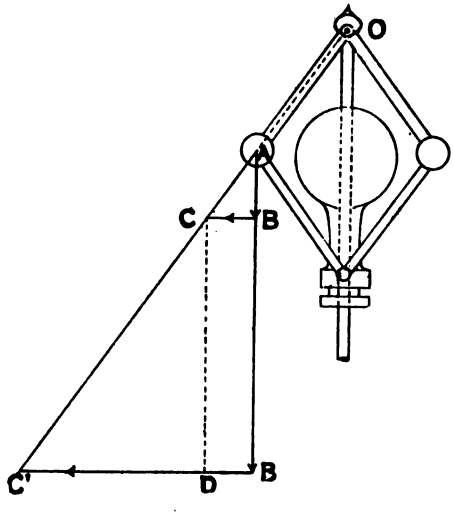

Fig. 5.

One of the properties of the *parabola* is that its subnormal is a constant quantity, hence governors have been designed in which the balls are constrained to move in a path approximately parabolic in form. A very common form for this type is known as the *crossed* arm, and is shown in Fig. 6. Probably the

easiest way to design this governor is to first set out the parabola, select convenient positions for the extreme range of movements of the balls, then normals should be drawn to the curve at these points, and where they intersect will be the centre for a circular arc closely approximating to the desired curve.

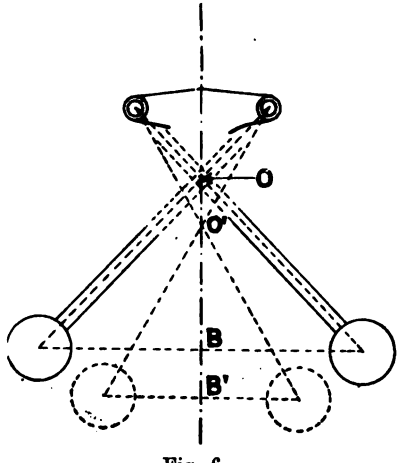

Fig. 6.

Messrs. Galloway have used a governor in which the balls move along a parabolic curve, and other firms have used designs obtaining a similar result.

If the governor was truly isochronous the least change of speed would cause it to move up or down through its whole range, and because such changes of speed are constantly occuring, the governor would be in constant movement, or *hunting* about, so that the steam inlet valve would be either wide open or shut, and the speed of rotation constantly rising and falling, due to the governor exaggerating the adjustment of the steam supply necessary to preserve the balance between effort and resistance.

Engineers usually design their governors to have the maximum sensitiveness possible and then add some artificial resistance to

reduce it! so as to avoid the defect of hunting. The better way surely is to design the governor with the necessary stability and avoid brakes, resistances, dash-pot, &c., as a redundant member of the mechanism, costing money to design, manufacture, and to maintain.

A very convenient way of examining the relative merits of pendulum governors is to construct the diagram of forces for the equilibrium of the ball in any position. For example let O A in Fig. 7. represent the position of the ball arm running steadily, the weight of the ball is represented by A B, and the centrifugal force B C, and A C = pull in arm. Now let the governor be loaded with a central mass so that its effective weight at the ball centre = B B′, the centrifugal force is unaltered in magnitude and = B′C′, then the tension in arm must = A C′ and the ball arm must take a position A′O, such that A′O and A C′ are

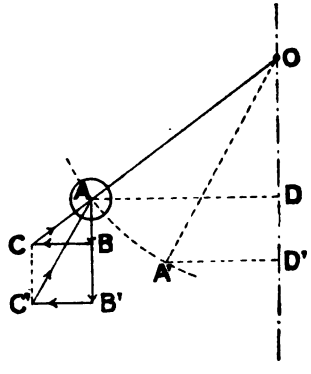

Fig. 7.

parallel. The height of the governor has been increased therefore from O D to O D′ and it is clear that

$$\frac{O\,D'}{O\,D} = \frac{A\,C'}{A\,C};$$

that is the height is increased in direct proportion to the increase of weight.

Hitherto no account has been taken of the influence of the resistance due to the friction of the mechanism, and by means of these diagrams it is easy to understand its effect upon the governor. Since friction always opposes motion, if in Fig. 8

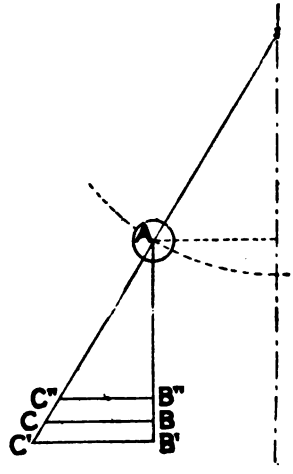

Fig. 8.

the condition of steady speed is shown by the position of the ball arm and by the triangle of forces A B C, then let the frictional resistance = B B′ = B B″ on the same scale that A B = weight of the ball and load. If more load should come on to the engine, the speed must fall until the centrifugal force has been reduced to B″ C″ before the ball can commence to move downwards; similarly if the load be reduced the engine will increase in speed until the centrifugal force = B′ C′, when the balls will be just able to commence moving upwards. Hence the ratio of A B and B B′ or B B″ is a measure of the *powerfulness* of the governor, and another advantage of the loaded governor is made apparent.

This will be more readily appreciated if a numerical example be taken. Let N_1 = the maximum number of revolutions, corresponding to the centrifugal force B′ C′, and N_2 = the minimum

number of revolutions corresponding to the centrifugal force B″ C″, whilst N = number of revolutions corresponding to the centrifugal force B C, then

$$N_1 = N\sqrt{\frac{B'C'}{B\ C}}\ ;\ \text{and}\ N_2 = N\sqrt{\frac{B''C''}{B\ C}}\ ;$$

$$= N\sqrt{\frac{A\ C'}{A\ C}}\ ; \qquad = N\sqrt{\frac{A\ C''}{B\ C}}\ :$$

Let A C = 40lbs., and the resistance C C′ or C C″ = 10lbs., then the ratio of the speed may increase before the governor will respond

$$= \sqrt{\frac{50}{40}} = 1{\cdot}118, \text{ say } 12\,\% \text{ increase,}$$

and the ratio in which the speed may decrease

$$= \sqrt{\frac{40}{80}} = 1{\cdot}154, \text{ say } 15\,\% \text{ decrease.}$$

Now let the governor be loaded with a weight of 80lbs. and these ratios of increase and decrease become respectively 4 %, and 4·4 %. If the frictional resistance remained constant, the speed of the engine might be permanently increased or decreased within those limits without any movement of the governor taking place. But practically the thrust or tension due to the load on the controlling gear varies during each stroke, the frictional resistance will be a variable one, and the delay in governor action will be reduced or increased proportionately.

Another important source of retardation of movement is due to the inertia of the total mass of the parts set in motion. This may be in very large governors a serious item. It is an easy—although possibly tedious—problem to solve. All the masses should be reduced to their equivalent at the collar say, and then the acceleration determined from the force available for the purpose.

Take the case of a governor with a movement of the collar of about 1½ins. for a reduction or increase of half load, and suppose

the mass of the counterpoise, attachments and spindle is equivalent to a mass of 400lbs. attached to the sliding collar. If the engine be making 60 revolutions per minute and the cut-off takes place about 33% of the stroke normally then the maximum time available is 66% of the time of one stroke. Now the time per stroke is one half of a second and 66% of this is one third of a second; hence the mass of 400lbs. must be set in motion with a velocity increasing to a maximum and diminishing to zero, describing $1\frac{1}{2}$ins. in one-third of a second. Assuming that the rate of acceleration of the mass is uniform for the first $\frac{3}{4}$in., and that the rate of retardation is similarly uniform for the next $\frac{3}{4}$in., then the rate of acceleration will

$$= \frac{2 \times 36}{16} = 4{\cdot}5,$$

and the force necessary to produce this will

$$= \frac{400}{32{\cdot}2} \times 4{\cdot}5 = 55{\cdot}91\text{lbs.}$$

Of course, this result is put forward only for the purpose of emphasizing the necessity for keeping down mass in the design of the moving parts in governor design, if promptness is sought. The figures are not absolutely accurate.

The actual state of affairs is probably something as follows:— First let the engine be running steadily until some extra load is thrown on, then the engine commences to slow down at a rate dependent upon the mass of the fly-wheel, until the governor has increased the steam supply by the required amount to balance the load. So soon as the speed begins to fall the centrifugal force also commences to fall, and equilibrium is destroyed. When the force necessary to overcome friction is available the balls would fall to the new position, but a further reduction of speed is necessary to obtain the force requisite to overcome the inertia of the parts before movement of the gear can commence. It is then probable that momentum will carry

the gear a little too far, which will result in a momentary increase of speed beyond the normal, a secondary bad effect of much mass in the gear.

To meet this defect springs are employed by many designers, for the mass of a spring is small compared with the load it can replace. An advantage of a spring is that by suitably arranging its stiffness, the *stability* of the governor can be assured without the use of any external damping apparatus.

The Hartnell type of spring governor has been very extensively used, and with the most satisfactory results in practice. It can be given almost any degree of isochronism desired, with great powerfulness. It can be used in any position, and has been adopted by high-speed engine builders with the happiest results. In Fig. 9. is reproduced the speed diagram in the case of some

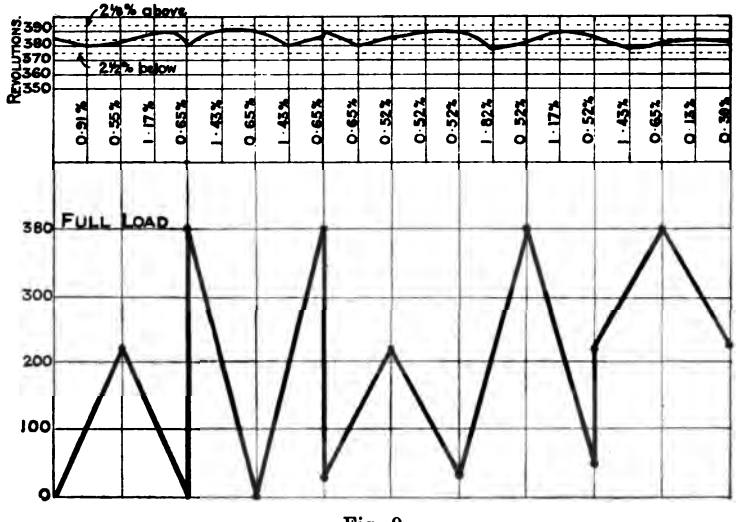

Fig. 9.

engines supplied for electric traction purposes by Messrs. Belliss & Morcom, of Birmingham.

The condition of equilibrium in this type of governor, is that the moments of the centrifugal force and of the spring shall

balance each other. Using the rotation of Fig. 10. it will be seen that

$$C \times OA = S \times OB,$$

and as usually OA = OB, this reduces to

$$C = S;$$

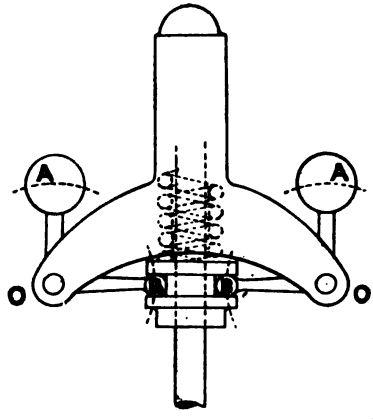

Fig. 10.

The effect of the weight of the arms must be considered, but no definite rules can be given, since the position and design of the arms varies, and it is a very simple matter to deal with.

In the above equation $C = \frac{w v^2}{g r}$, in which $\frac{w}{g}$ is a constant quantity, and $\frac{v^2}{r}$ is proportional to $\frac{r^2}{r}$ or r. The centrifugal force therefore *varies* as the *radius*, hence if the stiffness of the spring be such that it increases proportionately to the radius, then the governor will run steadily in any position at the same speed.

In order to obtain stability it is usual to arrange the stiffness of the springs, so that there is a definite position of the collar for any particular speed of rotation.

It is customary with many designers to attach the springs to the balls direct, one on either side, an arrangement that relieves

the pins of pressure, and consequently reduces friction. This arrangement is shown in Fig 11.

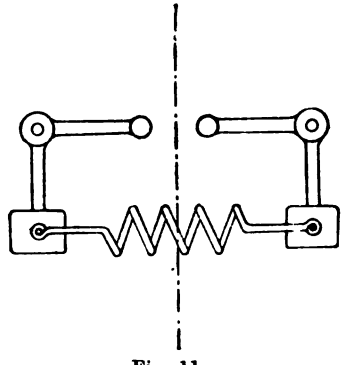

Fig. 11.

Another type of governor operates directly on the position of the eccentric operating the slide valve, and the mechanism is frequently placed in a drum or fly-wheel. Larger weights can be mounted in this way, so that a very powerful governor can be obtained. The only new feature however that needs noticing here is the use of the inertia effect of mass in motion, which is often employed in these governors. This will be

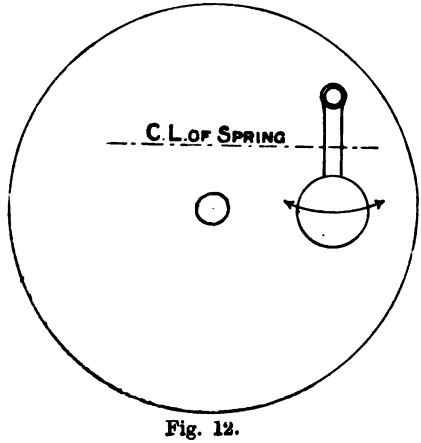

Fig. 12.

rendered clear if the three elementary arrangements of springs and weights be considered. In the first—illustrated in Fig. 12—the movement of the ball is radial, due to changes of centrifugal force; in Fig. 13 the movement of the ball cannot be affected by centrifugal force, but any increase in speed of the engine,

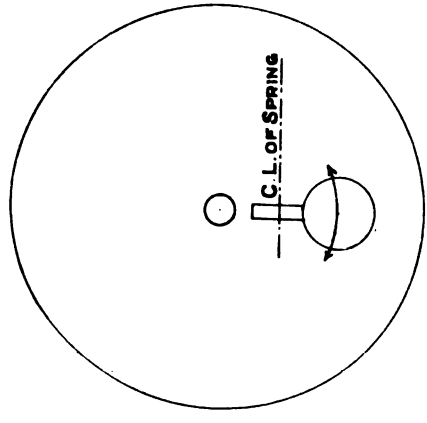

Fig. 13.

will cause the ball to *lag*, or if the speed decrease, the ball will over-run the wheel, or *lead*. This has been termed tangential acceleration, and the former effect radial acceleration.

The third arrangement possible is to pivot the mass at A, in Fig. 14., then any change of velocity of rotation of the wheel will cause the ball to rotate about the pin A, the motion of the tail altering the eccentricity of the eccentric accordingly. This may be termed *angular* acceleration. Fly-wheel governors using one or more of these principles are on the market, and excellent results are claimed for them, but obviously the same conditions must be fulfilled by them as in the rotating pendulum type in order that satisfactory results may be obtained.

Summing up the process of arranging for the regulation of a steam, gas, &c., engine, first a turning effort diagram is required,

and this must extend through a complete cycle, when *(a)* under full load, and when *(b)* running light. On this diagram a line showing mean resistance due to full load, also a second line representing the friction load only.

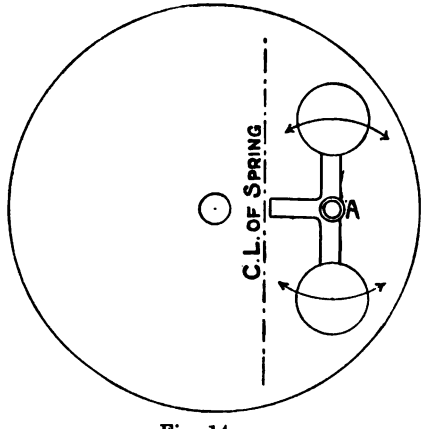

Fig. 14.

Next, the type of governor to be employed and the method of control, must be selected, either a trip gear, throttle valve, &c., so that the size of the parts can be fixed. Then an examination of the design in detail should be made, so that the combined effects of the frictional resistance of pins and connections, the inertia of the total moving parts, and the actual "pluck" of the "trippers," &c., may be estimated.

With this data available the "time lag" of the governor, may be guessed, and Figs. 15 and 16 constructed. In Fig. 15 the full load turning moment is laid down for half a revolution, and the light load turning moment for the next stroke. Then the

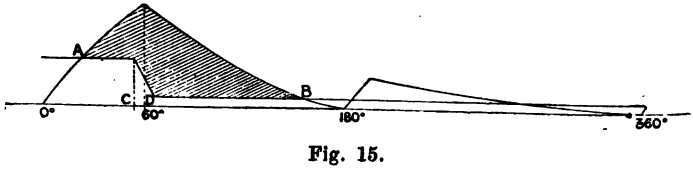

Fig. 15.

mean resistance due to full load is drawn up to a point before cut off, such, that the distance C D = the time lag of the governor, then the resistance will fall more or less quickly to no load, when the line will again become horizontal. The shaded area must then be measured, as it represents the excess energy that the fly-wheel will have to absorb without its speed exceeding the stipulated limit.

Fig. 16 represents the construction for the similar condition of things when full load is suddenly thrown on, and it is needless

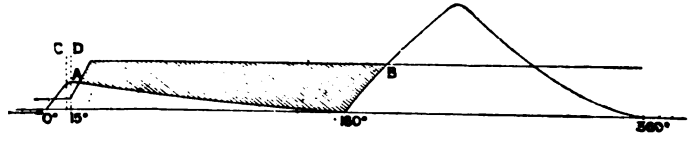

Fig. 16.

to say that the greater of the shaded areas in Figs. 15 and 16 must be taken when determining the mass of the wheel.

When designing a governor it is frequently the case that great efforts are made to obtain great sensitiveness and power, overlooking altogether the effect of the inevitable (as it cannot be eliminated) time lag of the mechanism. The rise of speed between the points A B in Fig. 15 will be such that the regulating gear will over-run its true position, which will lead to a wave on the Moscrop record above and below the mean speed. Similarly the fall of speed between A and B in Fig. 16 will lead to an excessive supply of steam with a consequent irregularity in speed until a final settlement has been effected.

Some such effect as this is undoubtedly inevitable, but if this undulatory action is not properly recognised when the design is being settled, its oversight will lead to much trouble when a case occurs of a load varying at some rate which is a multiple of the governor period, when building up will occur until the engine hunts to such an extent as to require attention.

Probably many have experienced this trouble of hunting, and if they have studied "forced vibrations" or "resonance" as electricians call it they will know that it is necessary to alter the period of one or other disturbance. Sometimes it is effected by putting the dash-pot out of operation, or increasing its effect. In other cases the reduction of the mass of the counterpoise, and altering the speed of the governor has been the cure. Each of these changes alters the "time-lag" in amount, but after a study of Figs. 15 and 16 it will be clear that if the fly-wheel power is *deficient* fluctuation of speed is certain to be large, and the fly-wheel may assist to intensify the undulations occurring.

Irregular running is a very complex question, and can only be successfully solved after the several factors concerned have been carefully studied, and each case of complaint must be separately treated.

The subject of "the regulation of speed" of engines is exceedingly interesting, whilst it is by no means so completely and finally settled as many believe, judging by the trouble it often entails in practice, and this is the reason why the Author has ventured to submit the subject for discussion.

APPENDIX.

Centrifugal force:—

Let W lbs. = weight of revolving mass.
N = number of revolutions per minute.
r = radius of centre of mass in feet.
g = the acceleration due to gravity.
F = the centrifugal force in lbs.

Then $$F = \frac{W v^2}{g r} = \frac{W}{g r}\left(\frac{2 \pi r N}{60}\right)^2;$$

$$= (0{\cdot}00034)\ W N^2 r;$$

Let W = 1lb., and r = 1ft., then

$$F = C N^2.$$

The following Table gives the value of F for values of N from 10 to 99, and other values can be obtained by shifting the decimal point.

	0	1	2	3	4	5	6	7	8	9
10	·034	·041	·049	·057	·067	·076	·087	·098	·110	·123
20	·136	·150	·164	·180	·196	·213	·230	·248	·266	·286
30	·306	·326	·348	·370	·393	·416	·440	·465	·491	·517
40	·544	·572	·600	·629	·658	·690	·719	·751	·785	·816
50	·850	·885	·920	·956	·991	1·029	1·065	1·104	1·143	1·183
60	1·224	1·266	1·301	1·35	1·39	1·44	1·48	1·52	1·57	1·62
70	1·66	1·71	1·76	1·81	1·86	1·91	1·96	2·02	2·07	2·12
80	2·18	2·23	2·28	2·34	2·40	2·46	2·51	2·57	2·63	2·69
90	2·75	2·81	2·88	2·94	3·00	3·07	3·14	3·20	3·26	3·33

EXAMPLE.—Let the weight of a ball = 20lbs., and the radius of the circle described be 9 inches, and the speed be 90 revolutions per minute.

From the Table, F for 90 revolutions = 2·75lbs. for 1lb. at 1ft., hence for this case

$$F = 2{\cdot}75 \times 20 \times 0{\cdot}75 = 41{\cdot}25\text{lbs.}$$

Suppose the speed be increased to 210 revolutions, then F for 1lb. at 1ft. = 15lbs., hence

$$F = 15 \times 20 \times 0{\cdot}75 = 225\text{lbs.}$$

Parabola. This curve is the locus of a point equally distant from a fixed right line (the directrix) and a fixed point (the focus).

The intercept on a line through the focus parallel to the directrix is always equal to twice the perpendicular distance between the directrix and the focus. See Fig. 17,

On Fig. 17 is shown the effect of change of centre of suspension which will repay examination. The effect of exceeding the proper deviation for the approximate centre of curvative, it will be seen, is to reverse the action of the governor, that is for a decrease of h, the balls must *fall*.

Fly-wheel Formulæ.—The total amount of energy absorbed by a fly-wheel during a change of speed from V to V_1 ft per second

$$= \frac{W}{2g} (V_1^2 - V^2) \text{ foot, lbs.}$$

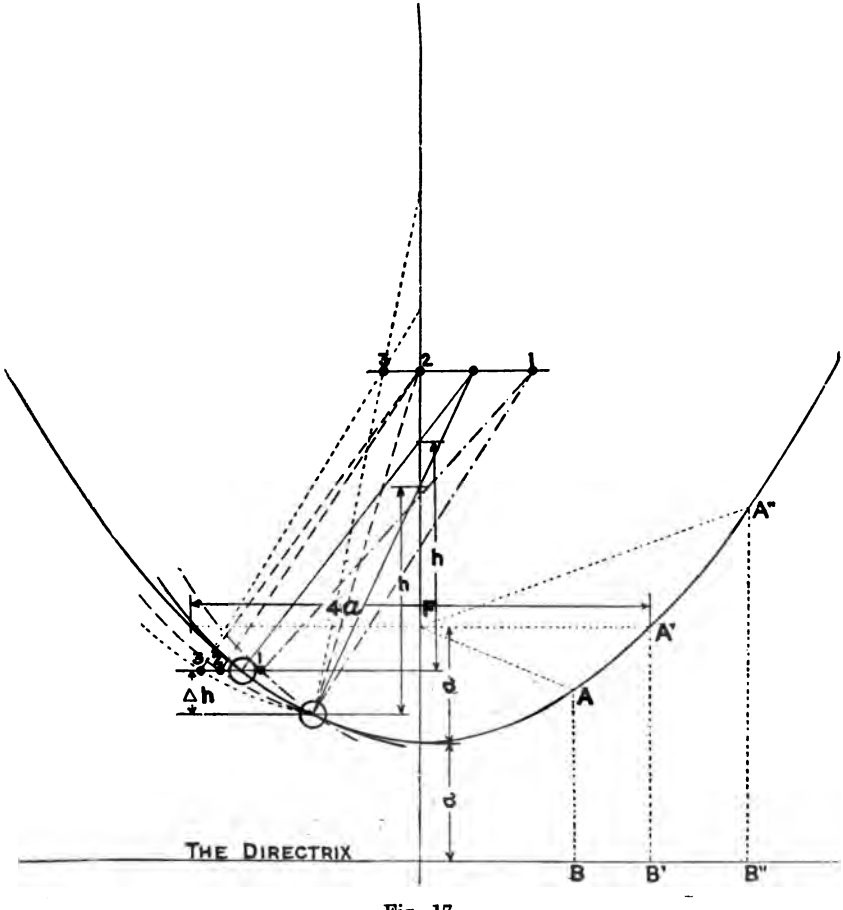

Fig. 17.

This quantity is the maximum area of excess or defect shown in Figs. 15 and 16, and may be called Δ E.

But $(V_1 + V) = 2V_0$ where V_0 = mean velocity, and if $kV_0 = (V_1 - V)$ then

$$\triangle E = \frac{W}{2g}(V_1^2 - V^2) = \frac{W}{2g}(V_1 + V)(V_1 - V)$$

$$= \frac{W}{2g} 2V^0 \; k \; V_0 = \frac{W}{g} k \; V_0^2 \; ;$$

and the weight of the rim required

$$= \frac{\triangle E \times g}{k \; V_0^2} \text{ lbs.}$$

Professor Unwin has given as suitable values for k the following:—

	k =
Engines Pumping.	$\frac{1}{20}$
,, Driving Machine Tools.	$\frac{1}{30}$
,, ,, Textile Machines.	$\frac{1}{40}$
,, ,, Spinning Machines.	$\frac{1}{50}$ to $\frac{1}{100}$
,, ,, Electric Generators.	$\frac{1}{150}$

If the rim be of cast-iron, the area required in square inches

$$= \frac{W \times 0{\cdot}051}{R} ;$$

where $R = \frac{R_1 + R_2}{2}$, that is the radius of the centre of gravity of the section.

Stress in lbs. per square inch section of rim due to centrifugal force for cast-iron

$$= 0{\cdot}001064 \; N^2 \; R^2 \; ;$$

where N = number of revolutions per minute, and R = mean radius of rim in feet.

Where a series of engines are being built, having the same steam distribution, and, therefore, having similar variations of turning effort, it is convenient to base the weight of rim upon the work done per revolution. Let E = work done per revolution

at full load, and n some number such that $n\,E = \triangle E$; then

$$n\,E = \frac{W}{g}\,k\,V_0^2$$

or the weight W

$$= \frac{g\,n\,E}{k\,V_0^2};$$

but g and n and k are constants for the case under consideration, hence if $\frac{g\,n}{k} = F$

$$W = F\ \frac{E}{V_0^2};$$

and the quantity F is frequently called the fly-wheel factor.

Where an existing engine is being replaced by another, it is necessary to discover the relative fly-wheel powers, and this factor method is convenient, since

$$\frac{F_1}{F_2} = \frac{W_1\,N_1^2\,E_2}{W_2\,N_2^2\,E_1};$$

where the subscripts denote either engine, numbers one or two respectively. Remembering that W is proportional to volume, the ratio of the factors may be readily determined, and a comparison of the probable steadiness of turning of the two engines made.

The formula

$$\triangle E = \frac{W}{2\,g}\,(V_0^2);$$

may be written thus

$$\triangle E = \frac{W\,N^2\,R_0^2}{5{,}874}.$$

Where R_0 = radius of gyration of rim in feet; then for any wheel $W\,R_0^2 / 5{,}874$ is constant. The useful relationship follows

$$\triangle E = \frac{W\,R_0^2}{5{,}874} \times N^2.$$

Suppose $W R_0^2 / 5{,}874 = 50$ for some wheel, then if the engine makes 100 revs. per minute the total energy stored

$$= 50 \times 100^2 = 500{,}000 \text{ ft. lbs.}$$

Again if the normal load of the engine is 120 HP at 100 revolutions, and the fly-wheel has to absorb the work done in one revolution, what would be the increase of speed?

$$\text{Work per revolution} = \frac{120 \times 33000}{100} = 39{,}600 \text{ foot lbs};$$

hence the total energy in wheel will be increased to 539,600 foot lbs. and

$$N = \sqrt{\frac{539600}{50}} = \sqrt{10792}$$

$$= 103{\cdot}8 \text{ per minute:}$$

an increase of nearly 4 %.

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DISCUSSION.

The PRESIDENT (Mr. W. Henry Hunter), in declaring the discussion open, said that Mr. Wells's highly skilled, but yet practical paper, did not offer much guidance as to the lines the discussion should take. Although not competent to speak as an expert, it seemed to him (Mr. Hunter) that the principles laid down were absolutely sound; mathematics could not go wrong, although they might be erroneously applied. He hoped that those members who wished to make any observations would either criticise the conclusions arrived at, the method by which they were arrived at, or would supplement them by their own personal experiences.

Mr. JOHN MITTON said that the speed regulation of engines was a very fascinating and interesting subject, and he thanked the author for the lucid manner in which he treated the portion of the subject chosen by him. Taking a wide view of the subject, he expressed some sense of personal disappointment in the limited nature of the paper, and said he had looked for higher attainments in the papers offered before this Association; what was given by the writer was given in an excellent manner, as it constituted an accurate statement of the main principles underlying the pendulum governors.

The comparative merits of pendulum governors versus spring governors is an important subject and is worthy of consideration. For many purposes a spring governor was much superior to the pendulum governor; its main advantage was that the possibility of regulating, varying, and controlling a spring governor were very great, and further it could be designed of greater capacity for doing external work per unit of speed fluctuation in a given space, and at less cost than the pendulum type. The dis-

advantage of the spring governor is that its springs are liable to break, but those who have had considerable experience of spring governors had learned to put absolute confidence in them. The spring governor has the disadvantage of possessing very little mass or total weight to overcome any impact which it may receive from the external resistance.

The pendulum governor's main advantage is that it has great mass within itself, and is consequently less disturbed by impact; it also is a coarse governor as usually designed and applied in practice, which coarseness ensures its stability. The pendulum governor had been extensively applied to large engines, but those were types of engines that could not be seriously experimented with, as in a cotton mill and similar industrial establishments experiments could not be made in the same sense that electric lighting high speed plant could be experimented with. Owing to the test plate facilities in engineers' workshops, the experience there gained had brought into the vision of practical engineering, possibilities of design that had resulted in attaining a higher perfection of governing than was possible out of a pendulum governor system.

A very important factor of governing was the character of the resistances the governor had to overcome. This was as important a problem as the design of the governor itself. Unfortunately the resistance was a neglected quantity; little was said about it, because it could not be analysed; it could not be mastered, and was the "great unknown" that lay in front of the problem of governing.

Looking into the positive geometrical quality of the resistances which a governor has to overcome it is found that for a governor controlling a Corliss gear the peculiar characteristic was that when the governor was in the bottom position and cutting off $\frac{7}{10}$ths, then, when a quarter way up it would be cutting off about $\frac{8}{10}$ths, and when half way up would be cutting off about

$\frac{1}{10}$th, and it would have to make the remaining half of its movement to get to the point of 0 cut off.

That characteristic, speaking in general terms, was common to all corliss gears, and therefore the problem was a universal one, and had to be tolerated or compensated for by the introduction of wrist plate movements between the governor bobbin and trip gear. On the other hand, in the case of a throttle system, with the governor in the bottom position and the equilibrium valve wide open, the position of governor for various loads is wholly dependent upon the size of equilibrium valve chosen; but assuming that an equilibrium valve is only just large enough to avoid a restriction of pressure with the governor in its bottom position and on full load, then with the governor half way up the load would be about $\frac{3}{4}$; and when the governor was three quarters way up the load would be about $\frac{5}{8}$; when it was $\frac{7}{8}$ up the load would be about $\frac{1}{4}$; when it was about $\frac{3}{32}$ of its movement upwards the load would be about $\frac{1}{10}$th, and when running no load it would be at the top, thus it will be seen that from no load to $\frac{1}{10}$th load requires a very small fraction of the governor's movement, say about $\frac{1}{32}$ of its full movement, whereas with the Corliss system the movement of the governor would be about $\frac{3}{8}$ of its full movement for the same load change.

A point in connection with governing he might mention was that electrical engineers often specified that the speed variation from no load to full load should be 2%; this under some conditions can easily be obtained, but under other conditions it is often a very difficult problem. He thought electrical engineers should not create a very difficult governing problem for the sake of small advantages in generator design, as they themselves had easier means of compensating for a fluctuation of speed to about 4 or 5%. If a plant was put down which under unfavourable conditions actually obtained 2% variation from no load to full load, it was such a fine thing to get that

the engine may soon lose its great merits and be on the border line of hunting, because no matter what was done with the governor, and how the details were combined, the obtaining of such fineness meant loss of governing power. Extreme sensitiveness of governing could not be obtained without loss of stability in some degree, and on that account he thought it would be wise for electrical and consulting engineers to ask for a coarser system of governing than usually specified.

Mr. JAS. G. WALTHEW said he wished to express his personal thanks to Mr. Wells for his admirable paper, which contained a great amount of valuable information.

He thought one point the author might have brought out with greater emphasis, was the superiority of the spring loaded type of governor, which did away with the friction obtained with any centre weight governor.

With regard to the sensitiveness of the governor, he agreed with Mr. Mitton that consulting engineers asked for absurdly fine governing, which could not be obtained with reliability.

There was, he thought, one important point worthy of mention in designing governors. We were apt to say, "We will design this governor for 2½% variation," because they were asked to do it. But with the engine running and the governor operating on a throttle valve, the range of the governor was curtailed, so that the action of the governor was not from top to bottom, but instead was probably from top position to a position halfway; this meant that if the governor were designed for 2½% variation, as there was only a working range of the governor equal to half that, the governor had only half the calculated variation; in other words, it made the variation only 1¼% instead of 2½%. In his own experience he had found that with a governor to give a variation of 1¼%, there was a certain amount of hunting.

Now the working conditions of that engine are such, that when owing to the high speed with which the gases could be passed through the throttle, with very little friction, it meant that when on full load the throttle only required to be half open intead of full open, as was theoretically calculated. Full open position was necessary in case of sudden load coming on, the throttle being then wide open to allow full charge entering the engine cylinder.

He would be glad if Mr. Wells would state what he considered the best variation suitable for driving alternators in parallel. His (Mr. Walthew's) own experience was that with alternators in parallel, sensitive governors were not required. What was necessary, he thought, was the governors of both machines should occupy the same relative positions according to the load; but if there was high sensitiveness, there was still greater likelihood of the alternators running out of step on varying load.

Mr. Wells had first condemned the dashpot, but afterwards had said that its only merit was that it checked the vibrations of the counterpoise. That point would not come up with regard to spring loaded governors; but he agreed with Mr. Wells that dashpots were certainly not required.

A mistake which he thought engineers in England made, was that each engine builder usually made his own governor. The design of governors, as the paper had shown, was a very complicated problem; and Germany had, he thought, shown the way by standardising their governors. No one in Germany would think of making their own governor; they obtained them from a specialist engineer, just in the same way that English engineers went to specialist makers of stop valves.

Mr. A. Saxon thought they would all admit that the crank-shaft governor which Mr. Mitton so highly advocated, was a good governor. Still, not one of the leading mill engineers in

Lancashire, who were successfully installing engines of all sizes for the driving of textile mills, had adopted that type and used it as a standard type of governor. There must therefore be some advantages in the pendulum type. Probably these were chiefly in the easy application of the compensating devices which had to be introduced to get the close governing which was demanded for fine spinning and other purposes in connection with manufacture.

One point for which thanks were due to Mr. Wells, was his analysis of the "periodic" and "non-periodic" changes in connection with steam engines. Too frequently these were mixed up. A person would bring a Moscrop diagram, and because there was a broad mark (you could have a broad mark, and still the governor would be running satisfactorily), would ask for the engine to be improved by putting on a new governor, whereas, as Mr. Wells pointed out, the difficulty might be in the engine construction, the poor fly-wheel, the unbalanced parts of the engine, and so on.

Respecting Mr. Walthew's remark that English engineers had made a mistake in each making their own type of governor, it should be borne in mind that as each engineer made a different kind of trip gear or arranged it differently, probably he had of necessity to himself design a governor which would comply and work satisfactorily with the type of trip gear used.

Mr. J. Vose, speaking in reference to Mr. Mitton's opening remarks, said that if the class of papers read before the Association were such that only those at the "top of the tree" could discuss, it would be of no advantage to those at the "bottom of the tree," or for those who, being engaged in certain branches of engineering, had joined the Association in order to obtain information respecting other branches.

The PRESIDENT (Mr. W. Henry Hunter) on proposing a vote of thanks to Mr. Wells, said that the subject of the paper to certainly ninety-nine out of one hundred constructional engineers, had not only elements of usefulness, but was fundamental in its value, and therefore, he did not agree with Mr. Mitton's suggestion that it should be put to one side. The paper was not intended for those at "the top of the tree" in designing governors, it was written for the general edification of the members.

Mr. G. J. WELLS, in his reply to the discussion, thanked the speakers for their patient attention and the kind reception they had given to his paper.

He did not think that, so far as his experience went, the pendulum type of governor showed any diminution in numbers. For some types of valve gear there was no doubt but that a "fly-wheel" governor offered advantages, and would be selected by the designer. He agreed with Mr. Mitton that a spring loaded governor had advantages over those loaded with a weight, and with increased knowledge of how to design and use springs, he felt that the springs would be more generally used. As a matter of fact the want of confidence in springs was mainly due to ill-usage. If the stresses were kept low then a spring would do good service, but the temptation to get a spring occupying a small volume was usually too great, and risks corresponding to the boldness of the designer were taken, and in the long run were paid for by the engine owner.

The peculiarity of Corliss engine regulation referred to by Mr. Mitton was due to the valve gear, and not to the governor employed. It was obvious that if tripping did not take place before the valve commenced to close, it could not take place at all during that stroke. But if the gear was arranged so that the release could be effected either during the opening or closing of

the valve, then there was no difficulty in arranging for a more equable distribution of cut-off in Corliss engines.

The difficulties incidental to throttle governing were very troublesome to deal with, but could be overcome if the underlying principles were once grasped. Mr. Mitton had given the clue to their solution in mentioning the amount of opening required for different proportions of load. If a multi-ported valve were used, in which the several ports had relatively some lead to each other, much finer regulation could be obtained. Usually the valve lift and the ratio

$$\frac{\text{area of throttle valve}}{\text{steam pipe area}}$$

were made much too great.

Mr. Wells regretted that Mr. Walthew thought that insufficient stress had been laid upon the advantages of springs, for several paragraphs are devoted to the consideration of the effect of inertia in increasing the lag of the governor, and the importance of eliminating mass from the moving parts as much as possible.

The amount of variation of speed necessary to ensure good running in operating alternators was a matter upon which no fixed rule, generally applicable, could be laid down. It was important, however, that in any power station where alternators had to run in parallel the governors should be similar in character, or some of the units would be doing more than their share of the load, and in extreme cases "motoring" might be taking place.

He was glad to find that Mr. Saxon agreed with him in thinking that the Pendulum governor was not yet obsolete, and that in practice it gave most excellent results. He thanked Mr. Saxon for his kind remarks.

As a general principle the author had attempted to state the principles that must be observed in the design of the gear for the regulation of engine speeds, and to exclude all reference to

patent devices however excellent they may be in any special feature. Any design to be of use must be based upon correct principles, and unless the full details of a specific design had been given it is difficult to see how the paper could have included such descriptions with advantage.

REINFORCED CONCRETE.

READ SATURDAY, 23RD FEBRUARY, 1907,

BY

Mr. H. N. ALLOTT, M.Inst.C.E.

(MANCHESTER).

Concrete has been in use as a material of construction from very early times, and its use has largely increased in recent years as it became possible to obtain cement of good and reliable quality with greater facility. Amongst its many advantages are the ease with which its constituent materials can be obtained and transported, its adaptability to form and comparative cheapness, its fire resisting qualities, and its great resistance to compressive strain. Its use has, however, been limited by its comparative weakness to tensile and transverse strain, but when reinforced by iron or steel to withstand these strains its usefulness is largely increased, and it can be used for many purposes not otherwise possible.

In 1854, Mr. Wilkinson, of Newcastle-on-Tyne, took out a patent for fire resisting floors, of which the material was concrete reinforced by the use of iron bars or wire ropes, but it was not until 1890 that the system received much attention, when M. Monier, of Paris, built an arched bridge in Germany of concrete reinforced by the insertion of a network of bars near the intrados and extrados. This bridge was 132ft. span, 14ft. 8in. rise, and only 10in. thick at the crown, and was followed up in Switzerland by a bridge of three spans of 128ft. each, 11ft. rise and 6¾in. thick at the crown. Since that time great progress has been made and the subject has received close attention from many engineers.

On the Continent and in America, reinforced concrete has been largely and increasingly used for the construction of complete buildings, bridges, chimneys, retaining walls, sewers, warehouse floors, girders, columns, piles, &c., but in this country its adoption has up to now been to some extent limited, possibly by our innate caution and also by the difficulties which the building bye-laws of the local authorities place in the way of its use. Its use is, however, growing rapidly, and in this district we have examples in the large new transit sheds of the Ship Canal Company visited last year by the members of this Association, bridges at Liverpool and Rochdale, together with other structures of more or less importance.

Abroad, reinforced concrete is now fully recognised by the authorities as a proper material of construction, and in many places stringent regulations have been drawn up to govern its use, and it is quite time that a similar state of affairs existed in this country, as no material or method of construction requires more careful design or consideration.

The materials to be used for the concrete must be all of the best quality, as on this portion of the work the safety of the whole structure depends. The stone or other aggregate must be perfectly clean, and broken to about ¾in. gauge, the sand perfectly clean and sharp, and the cement slow or medium setting Portland cement of good quality.

The steel is generally ordinary mild steel having an ultimate tensile strength of from 27 to 31 tons per square inch, although in America steel of 50 tons per square inch is used in bars of special shape to prevent slipping.

The concrete is usually mixed in not weaker proportion than one part of cement to two parts sand and four parts stone, although in America it is frequently mixed one part of cement to nine parts of stone and sand. The six to one mixture is however considered in this country more suitable, and it is

interesting to note that the new San Francisco bye-laws provide that the concrete shall not be mixed in less proportions.

The absolute proportions of the sand and stone are regulated by the size and shape of the stone, the object being to get sufficient fine material to fill the voids and thus form a dense and impervious mass. The concrete should be moderately wet, as this gives more solid work and better adhesion to the steel.

When steel and concrete were first brought into combination fears were expressed that temperature variations would lead to disintegration, and also that the steel embedded in the concrete would suffer from corrosion. Both these fears have, however, been shewn to be unfounded, careful experiments having shewn the coefficient of expansion for concrete to be ·0000055, whilst that of steel and iron is ·000006, and steel which has been embedded in concrete for years has been found on removal to be free from rust, even when the concrete has been exposed to the action of water, as in weirs, sewers, and pipes.

COEFFICIENTS.

The ultimate compressive strength of 6 to 1 concrete is given by various authorities as from 2,000lbs. up to 3,000lbs. per square inch. M. Christophe, the Belgian authority, gives the compressive strength of 5 to 1 concrete as 2,100lbs., and as the conditions under which test specimens are made are very different from those occurring in actual work, it is advisable to take the lower figure of 2,000lbs. per square inch, although it will be advisable in all works of importance to make tests from the actual materials to be used in the work so as to obtain the correct value.

The working stress on the concrete may be taken as $\frac{1}{6}$ of the ultimate strength

$$\frac{2{,}000}{6} = 333\text{lbs. say } 350\text{lbs. per square inch.}$$

for parts in direct compression as piles, arches, walls, &c., and

$\frac{1}{5}$ of the ultimate strength for beams, floors, roofs, &c., which are subject to bending stresses

$$\frac{2{,}000}{5} = 400\text{lbs. per square inch.}$$

In the case of warehouses or structures subject to steady loads, these stresses may be taken as $\frac{1}{5}$ and $\frac{1}{4}$ of the ultimate strength, or 400lbs. and 500lbs. respectively.

The tensile strength of concrete has been found by experiment to be $\frac{1}{10}$ of the compressive strength, which gives an ultimate tensile strength of 200lbs. It is usual however to neglect the tensile strength of the concrete, relying altogether on the steel for the resistance to tensile strains. This is to be recommended, as it simplifies the calculations and is also on the side of safety.

It may here be noted that, whilst ordinary concrete will not stand an elongation of more than 1 : 10,000 without cracking, when combined with steel it is stated to support an elongation of 1 : 1,000 without cracking.

This greater elongation is accounted for by the supposition that the reinforcement distributes the elongation over the entire length, whilst with ordinary concrete the elongation is confined to the point of rupture.

On this question there is considerable difference of opinion, M. Considere stating that cracks do not occur, whilst experiments made by Prof. Turneaure, of Wisconsin University, seem to show that they do. In any case, it is evident, that the greater part of the concrete on the tension side of a beam must be so stretched or cracked as to be incapable of offering any considerable tensile resistance, and it is therefore correct practice as above stated to neglect the tensile resistance of the concrete.

The shearing strength, and the adhesion between the steel and concrete, may be taken as equal to the tensile strength

which with a factor of safety of 5 gives a working stress of 40lbs. per square inch.

It is, however, advisable to introduce special reinforcement to resist the shearing forces, and in most instances to neglect the shearing strength of the concrete, which in the case of beams will be affected by the stretching or cracking on the tension side before referred to, and it has been found that beams so reinforced give better results than those in which longitudinal rods alone are used.

The adhesion is a variable quantity, and depends on the shape of the steel employed and on the wetness of the concrete. The concrete should be moderately wet when put in position, as this increases the adhesion, and it is found that round bars give better results than square or other ordinary forms.

The adhesive stress of 40lbs. per square inch will in most cases be sufficient to develop the stresses in the reinforcement, but if not, the additional amount must be provided for, either by the use of bars of special form, or by other means, and it is laid down in the German regulations for reinforced concrete construction, that the bond shall be as far as possible of a mechanical nature.

In this Country and on the Continent as previously stated it is usual to use for the reinforcement mild steel, the ultimate tensile strength of which may be taken as 27 tons, or about 60,000lbs. per square inch with an elastic limit of 16 tons or 37,000lbs. per square inch.

In America, steel of 50 tons per square inch tensile strength, with an elastic limit of 27 tons per square inch in bars of special form to ensure non-slipping is frequently used; many arguments however can be brought forward in favour of either material and for most purposes mild steel can be equally well employed.

It may here be stated that the elastic limit is really the governing quantity in considering the strength of a reinforced concrete structure and that the calculations should be made on this basis instead of on the ultimate strength of the material as is sometimes done. The reason is, that as soon as the steel passes the yield point, the modulus of elasticity drops suddenly and the steel begins to draw out rapidly, which alters the position of the neutral axis, destroys the concrete in tension and alters the distribution of the compressive stresses. The elastic limit therefore, really marks the ultimate strength of the work, and the working stress is commonly taken as $\frac{2}{5}$ of this or about 15,000lbs. per square inch for mild steel of 27 tons per square inch ultimate strength.

Recapitulating, the working stresses may be taken as follows :—

	CONCRETE.		
Direct Compression for Columns Piles, Walls, &c. ..	350lbs. per square inch. 400lbs. for steady loads as Warehouses, &c.		
Compression for Beams, Floors, &c.	400lbs.	Do.	do.
	500lbs.	Do.	do.
Tension	40lbs.	Do.	do.
Shear	40lbs.	Do.	do.
Adhesion	40lbs.	Do.	do.
	STEEL.		
Tension	15,000lbs.	Do.	do.

It should be remembered in using these figures that it is the safest practice to neglect the tensile and shearing strength of the concrete, and that the adhesion may be affected by various circumstances and therefore requires particular consideration in each special case.

The modulus of elasticity of steel is well determined at about 30,000,000, but as may be expected, the modulus in the case of concrete is not so definitely ascertained, and it is taken by various authorities as from $\frac{1}{10}$ to $\frac{1}{15}$ of that of steel.

M. Christophe, in Belgium, Professor Brik, in Austria, and Professor Hatt, in America, after fully discussing the matter decide that this may be taken as $\frac{1}{10}$, whilst the New York regulations fix it at $\frac{1}{12}$, the Prussian and San Francisco regulations at $\frac{1}{15}$ and the American Fire Office rules at $\frac{1}{18}$.

The French rules state that whilst the ratio of the moduli of elasticity of concrete and steel has been found experimentally to be equal to $\frac{1}{10}$, this figure should not be used indiscriminately, and the value may vary from $\frac{1}{8}$ to $\frac{1}{15}$ according to the diameter of the longitudinal reinforcement and the spacing of the transverse reinforcement. It may therefore be safely taken in ordinary cases at the mean figure of $\frac{1}{12}$.

METHODS OF CONSTRUCTION.

Beams and Slabs.—In the case of beams and slabs it is clear that the reinforcement should be placed as near as possible to the edge exposed to tension, taking care that a sufficient thickness of concrete is allowed to protect the steel against corrosion and fire. This thickness is usually from one to one and a half inches, but two inches is desirable and the extra cost is not very great.

The arrangement of the tension reinforcement for a beam supported only at both ends will therefore be as shewn in Figs. 1 or 2, whilst where the beam is fixed at the ends or continuous over supports, the tension is on the top for about a quarter of the span and the reinforcement is arranged as shewn in Figs. 3, 4 and 5. Additional resistance to shearing is obtained by the addition of smaller vertical or inclined rods as shewn in Figs. 6 and 7. Many formulæ have been proposed for the calculation of beams and slabs and it is impossible and unnecessary within the limits of a short paper to compare them, the question being more safely and simply dealt with by the ordinary elastic theory of beams as adopted by many writers on

the subject, which method is also adopted in most regulations for reinforced concrete.

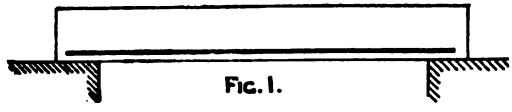


FIG. 1.

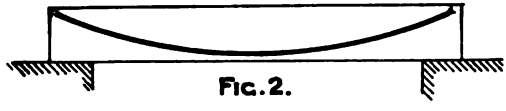


FIG. 2.

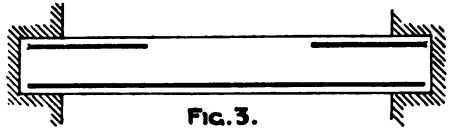


FIG. 3.

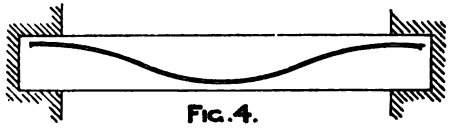


FIG. 4.

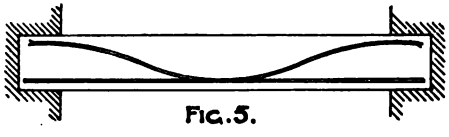


FIG. 5.

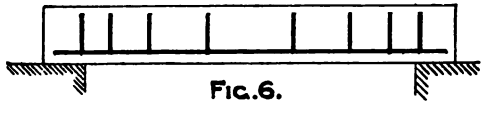


FIG. 6.

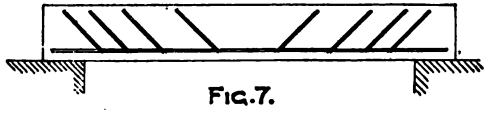


FIG. 7.

In dealing with the question in this manner the following assumptions are made :—

1. A section plane before bending remains plane after bending.

2. It has been shewn by experiment that the modulus of elasticity of concrete varies, its value being decreased as the stress increases, but it is assumed that within working limits the relation of stress to strain remains constant, and may be represented by a straight line. It may here be mentioned, that although this has been shewn by experiments to be a curve approximating to a parabola for ultimate stresses as shewn in dotted lines Fig 10, the relative difference when taken as a triangle is only 2%, and is on the side of safety.

3. The resistance of the concrete to tension is not taken into account.

Taking as an example a beam with a single reinforcement as Fig. 8.

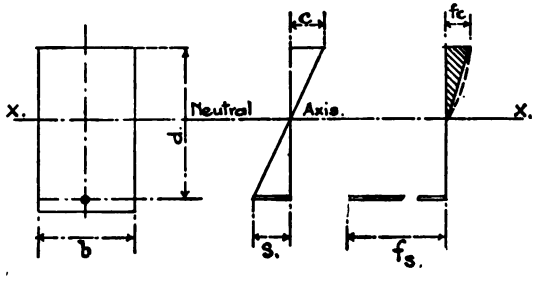


Fig. 8. Fig. 9. Fig. 10.

The strain or deformation diagram will be as shewn in Fig. 9 s being the unit elongation due to the working tensile stress f_s, and c being the unit deformation due to the working compressive stress f_c.

The corresponding stress diagram will be as shewn in Fig. 10.

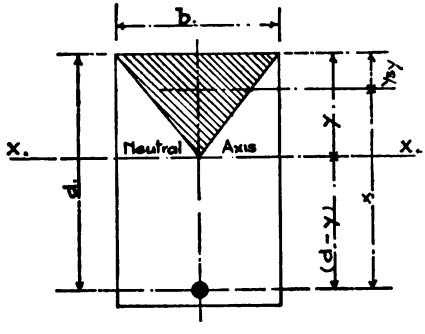


FIG. 11.

b = breadth of beam in inches.

d = depth of beam in inches to centre of reinforcement.

y = distance of neutral axis from extreme top fibre.

$d-y$ = distance of centre of gravity of reinforcement from neutral axis.

x = height of centre of gravity of compression area above centre of reinforcement.

a = area of reinforcement.

f_c = working compressive stress in concrete.

f_s = working tensile stress in steel reinforcement.

E_c = modulus of elasticity of concrete.

E_s = modulus of elasticity of steel.

The calculations of a beam are then as follows:—

It is first necessary to find the position of the neutral axis, and as the total tensile and compressive stress must balance, we have (see Fig. 11.)

$$(a) \qquad \frac{by}{2} \times f_c = a \times f_s$$

and as the strain is proportional to the distance from the neutral axis

$$f_c : f_s :: E_c \text{ strain} : E_s \text{ strain} :: E_c y : E_s (d-y)$$

we have therefore the equation

$$(b) \qquad \frac{f_c}{f_s} = \frac{E_c y}{E_s (d-y)}$$

or substituting the values for E_s and E_c we have when $\frac{E_c}{E_s} = \frac{1}{12}$

$$\frac{f_c}{f_s} = \frac{1y}{12\,(d-y}$$

substituting in equation (a) we have

$$\frac{by}{2} \times y = a \times 12\,(d - y)$$

$$\therefore \frac{by^2}{2} = 12ad - 12ay$$

$$\therefore by^2 = 24ad - 24ay$$

$$\therefore by^2 + 24ay = 24ad$$

$$(c) \qquad \therefore y^2 + \frac{24ay}{b} = \frac{24ad}{b}$$

By substituting the values of a, b, d, in the case under consideration the equation can be easily solved as a simple quadratic and the position of the neutral axis determined.

The percentage of reinforcement will be

$$\frac{a}{bd} \times 100$$

and in Fig. 12 is given the position of the neutral axis for various percentages.

The sum of the compressive stresses being represented by a triangle, the position of the centre of gravity will be $\frac{1}{3}y$ below the top of the beam, and the depth for calculation will be $d - \frac{1}{3}y = x$.

The moment of resistance of the beam will be

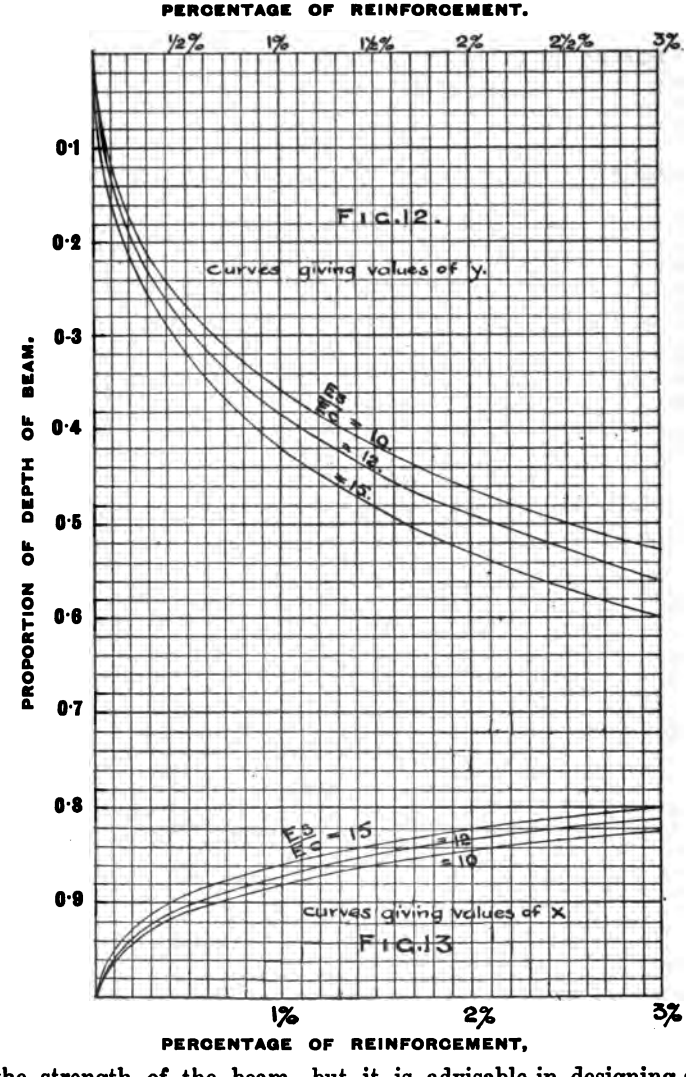
$$(d) \qquad R_c = \frac{by}{2} \times f_c \times x$$

for failure by compression or crushing of the concrete, and

$$(e) \qquad R_s = a \times f_s \times x$$

for failure by tension or stretching of the steel.

The values of x for various percentages of reinforcement are given in Fig. 13. The smaller of these two amounts determines



the strength of the beam, but it is advisable in designing a structure that the moment of resistance for failure by tension

should be the smaller, so that the beam would fail by tension and give warning by the formation of cracks in the lower portion.

When a portion of the floor slab is taken into account, the position of the neutral axis and the moment of resistance are determined in a similar manner.

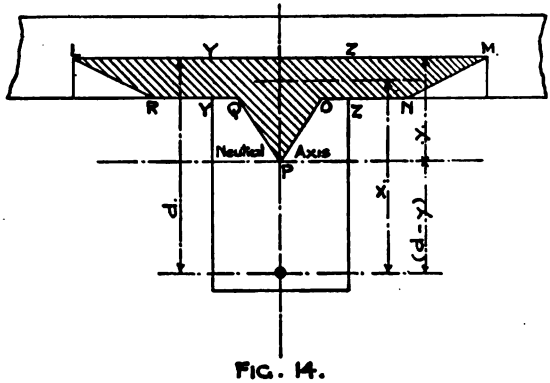


FIG. 14.

In this case it is probably better to omit from the calculation the top half of the slab, which is subject to tension.

The compression area will be represented by the area L M N O P Q R in Fig. 14. It is necessary to ascertain that the stresses represented by the areas L R Q Y and M N O Z do not exceed the safe shearing resistance of the concrete on lines Y Y and Z Z respectively and that the stresses represented by the figure L R N M do not exceed the safe shearing resistance of the concrete on line Y Z. Should the beam be provided with reinforcement at the top as well as at the bottom, in calculating the position of the neutral axis the area a^1 of the top reinforcement may be replaced by an additional area of concrete equal to

$$a^1 \times \frac{E_s}{E_c} = 12a^1 \text{ when } \frac{E_s}{E_c} = 12$$

The moment of resistance of the beam must of course equal the bending moment M, which equals when W = the distributed load in lbs. and l the span in inches.

For a supported beam $\frac{wl}{8}$

For a fixed or continuous beam $\frac{wl}{12}$ at supports.

$\frac{wl}{24}$ at centre.

In the case of continuous beams in floors which may not be loaded over their whole area, the beams are generally considered as partially fixed and the bending moment at centre should be taken as $\frac{wl}{10}$

The calculations for slabs are made in a similar manner, but if square and supported on all four sides, a slab reinforced in both directions is twice as strong as a slab supported on only two sides; if the length is however more than twice the breadth no gain in strength is obtained.

It is found that a beam only reinforced longitudinally is not as strong as a beam reinforced in addition by vertical or inclined stirrups or rods placed as shewn in Figs. 6 and 7 and that it fails by cracks extending from the lower side near the supports and inclined upwards towards the centre of the beam. It is evident that the increments of stress in the tension and compression members of the beam must be transmitted to them by the shearing stresses in the middle portion. Further reinforcement is therefore added to act in the same way as the ties in the web of a lattice girder, the concrete acting as the struts.

This reinforcement, if vertical, is frequently simply bent round the horizontal reinforcement and therefore free or loosely attached, but many engineers prefer to use fixed stirrups inclined at an angle of 45° upwards towards the supports,

which is the line of the tension component of the shearing stresses, and there appears to be little doubt that this practice is correct, although much satisfactory work has been carried out with the use of the vertical stirrups. Capt. Sewell, one of the leading authorities in the United States, is a strong supporter of inclined fixed stirrups, and Fig. 15 shows an arrangement

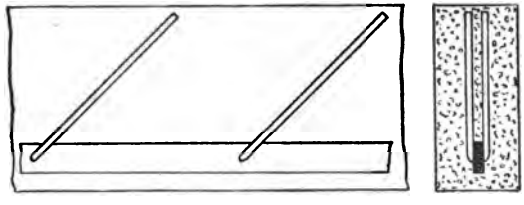


FIG. 15.

designed by him, the stirrups consisting of round bars passed through holes in the longitudinal reinforcement. Their value is borne out by the *tests made by the French Government Laboratory, which shew that the strength of beams tested with fixed stirrups, inclined at 45° as shewn in Fig. 16,

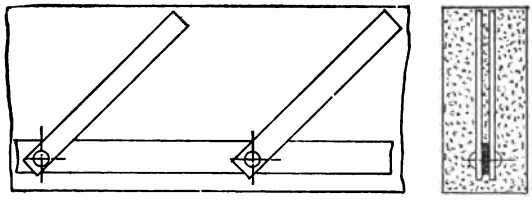


FIG. 16.

is about 20% greater than that of similar beams with loosely attached vertical stirrups. It was also found that the failure of the former was gradual, giving ample warning by excessive flexure, whilst the latter failed by shear

*Concrete and Constructional Engineering, May, 1906.

and gave little warning. It was further observed that the loose stirrups had slipped wherever a crack occurred whilst in the other the stirrups remained in their original positions.

The strength and number required of the stirrups may be obtained from the ordinary shearing force diagram of the beam, the stirrups being more closely spaced or their section increased as found necessary near the supports, the distance apart increasing as they approach the centre of the span.

The strength and number of the stirrups may also be calculated in the same manner as the web members of a lattice girder.

The ends of the steel reinforcement of the beams are usually either bent over, fishtailed, or provided with a washer.

Columns.—It is found, on testing a short thick column of concrete in the usual manner, that failure takes place by shearing on lines inclined to the direction of the stress. Experiments made however in France and Germany, shew that this mode of failure is due to the friction exerted between the ends of the column and the plates transmitting the pressure, it being found when these surfaces are greased, that failure takes place on lines parallel to the line of thrust.

M. Considere found that the hooping or spirally winding with steel of concrete columns greatly increased their crushing strength, and *tests made at the Watertown Arsenal, U.S.A., on a large number of columns, 8ft. in length and 10 and 12ins. in diameter made of 6 to 1 rock concrete give the following results:—

	Crushing Strength in lbs. per sq. in.
Plain Column	1413
13 Hoops	2232
13 Hoops and 4 longitudinal angle bars	3029
25 Hoops	3428
25 Hoops and 4 longitudinal angle bars	4189
47 Hoops	5289

* Paper by Mr. James E. Howard, *Engineering Record*, July 14, 1906.

The hoops used in these tests were 1·5 × 0·12in. in cross section lapped and riveted at joints, and the results shew that both the hoops and the longitudinal reinforcement assist in increasing the strength of the columns.

The general American practice with regard to columns, is that the least dimension should not be less than $\frac{1}{12}$ to $\frac{1}{15}$ of the height, whilst Continental practice permits of the use of more slender columns, providing calculations are made for flexure when necessary.

The first named practice is the better, and is usually followed in this Country, and if the proportions given above are not exceeded it will be unnecessary to calculate for failure by flexure, and the working stresses previously given for direct compression may be employed.

In making the calculations for a reinforced concrete column it must not be forgotten that the stresses on the two materials can only be proportional to their respective moduli of elasticity, and when $\frac{E_s}{E_c} = 12$, as is assumed in this paper, the stress on the longitudinal reinforcement will be twelve times that on the concrete. Taking A as the area of the concrete, a as the area of the steel in the column under consideration, and f_c as the working stress on the concrete, the safe load will be as given in the following equation :—

$$\text{Safe load} = f_c \left(A + \frac{E_s}{E_c} a\right)$$

$$= f_c \left(A + 12a\right) \text{ when} \frac{E_s}{E_c} = 12.$$

Reinforced concrete columns are generally made square for convenience in moulding, and the simplest form consists of a square with a steel rod at each corner, hooped at intervals, or spirally wound with rods of smaller diameter or flat bar. In place of the hoop or spiral winding, expanded metal or wire

lattice is sometimes used. When hoops are used their distance apart should not exceed the least dimension of the column, and the pitch of the spiral winding should not exceed one third of the least dimension of the column.

The spacing of the hooping or winding is usually made smaller at the ends. Should the load to be carried necessitate the use of additional longitudinal reinforcement, care must be taken to see that this is not spaced too close to allow of proper manipulation of the concrete, and in no case should the distance between the bars be less than 6in. Sufficient attention is not always paid to this point, and if sufficient strength cannot be obtained in this manner, the dimensions of the column should be increased, or if space does not permit a steel column substituted. In many cases the joints in the vertical reinforcing rods are made by simply overlapping the ends of the rods, when it is evident that much additional stress must be put upon the concrete.

The best practice is when round or square bars are used to fit the ends of the rods with a sleeve, when a pat of cement between will provide a perfect bearing.

All joints in columns should be made at a floor level, or should be laterally supported, and the San Francisco regulations specify this, in addition to providing that all vertical supporting rods shall have a tight fitting sleeve at joints, except in the case of buildings where allowance must be made for wind pressure, where they shall be threaded and provided with screw couplings.

Proper provision must be made at the base for transmitting the load from the steel reinforcement to the concrete of the footings.

The columns should be bracketed or gusseted at the junction of beams to obtain additional area to resist the vertical shear of the connection, and to stay the structure laterally.

The number of systems of reinforcement which have been designed and which are in use, is very large, and it is only possible in this paper to briefly describe the principal systems which have been adopted in this country.

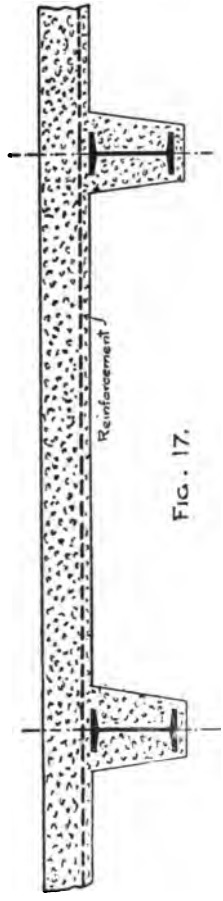


FIG. 17.

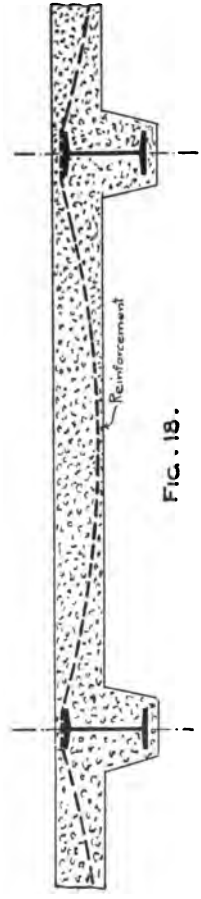


FIG. 18.

The usual methods of reinforcing floor slabs are shewn in Figs. 17 and 18 and the reinforcement usually consists of round rods, crossing each other, or of expanded metal, or woven wire lattice.

"MONIER" SYSTEM.

In the "Monier" system the rods are of different diameters, the larger diameter rods taking the longitudinal strain and the smaller rods which cross at right angles are connected at the

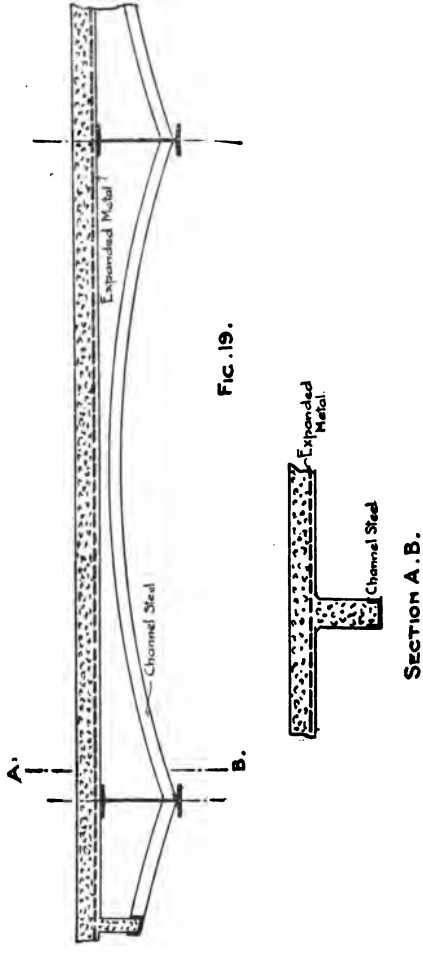


FIG. 19.

WIRE LATTICE.

intersections by tying with small wire, simply serving to keep the larger rods in position and to assist in the shearing resistance.

EXPANDED METAL.

Expanded metal, the invention of Mr. Golding, is formed by slitting and pulling out flat plates so as to form sheets with a diamond mesh, and is made in various thicknesses up to ½in. of varying size of mesh. It is applied to the reinforcement of slabs as shewn in Figs. 17 and 18, and is also used with the Golding channel arch system of floor shewn in Fig. 19.

Wire lattice of suitable strength is used in a similar manner.

The expanded metal or wire lattice can also be conveniently used to form a key for the covering of iron and steel girders and columns where these are used with a fire protecting coating, and can also be conveniently used for the reinforcement of walls and partitions, culverts, pipes, &c., and for other purposes.

"HENNEBIQUE" SYSTEM.

The "Hennebique" system is shewn in Fig. 20. The principal feature of the system consists in the vertical stirrups to resist the shearing forces in the beam. These are made of flat bars or round rods of small diameter bent round the straight reinforcement and extended nearly to the top of the beam or slab. The stirrups are more closely spaced towards the supports where the shearing force is greatest.

Flat bars are generally used and are now secured to the longitudinal reinforcement by a small pin which prevents displacement during construction.

When top reinforcement is used, additional stirrups extending downwards towards the bottom reinforcement, are provided.

The longitudinal reinforcement bars are arranged in pairs, one bar placed over the other, the top bar being bent up towards the supports to increase the shearing resistance and when the beam is continuous over the supports the rods are extended to further resist the reverse bending moment.

The columns and piles in this system are reinforced as shewn with vertical rods connected by loops of round bars of smaller

diameter. In place of the loops, flat bars, holed to suit the vertical bars, are sometimes used.

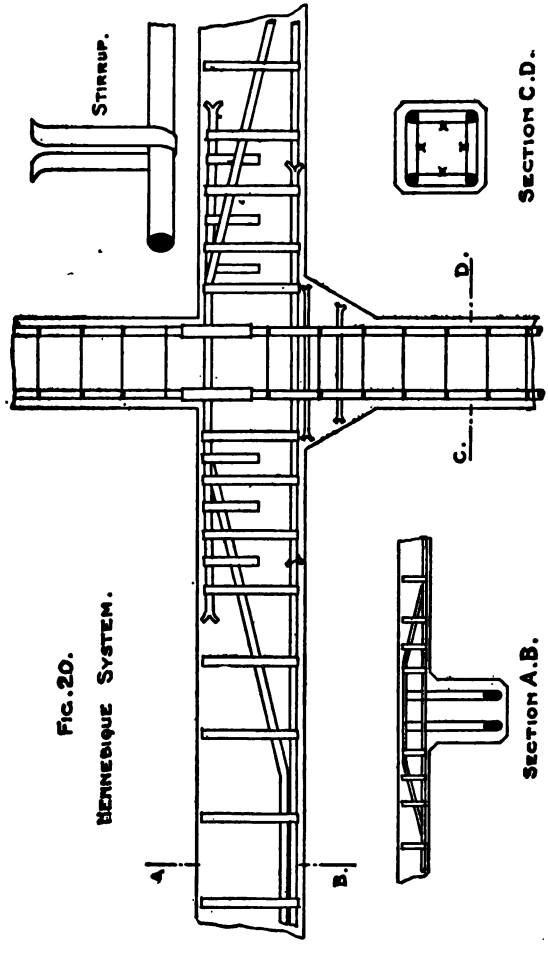


FIG. 20.
HENNEBIQUE SYSTEM.

Slabs are reinforced in a similar manner to beams, the longitudinal rods being straight and bent up towards the supports

alternately. Walls are constructed in the "Hennebique" system by placing rods vertically and horizontally. Of the vertical rods one system is placed on the outer face and one on

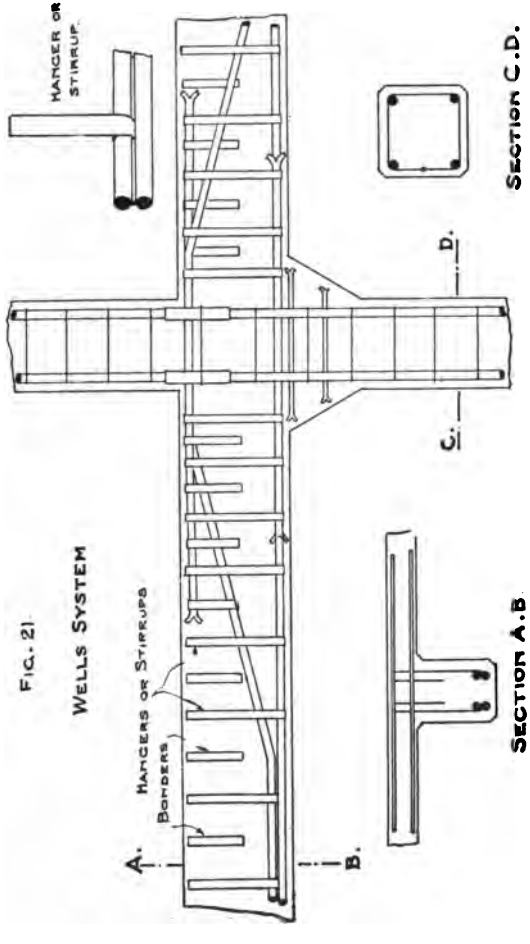


FIG. 21
WELLS SYSTEM

the inner side, stirrups tying each set with the opposite face. The longitudinal rods are placed in the centre of the wall.

"WELLS" SYSTEM.

The "Wells" system, shewn in Fig. 21 is the invention of Mr. E. P. Wells of London. In this system, a twin bar, resembling two rounds joined together by a thin web, is used for the longitudinal reinforcement of beams.

The web is sheared for a length of about one third of the span from each support, and one half of the bar bent upwards to increase the shearing resistance, and where necessary extended over the supports to take the reverse bending moment. The stirrups are arranged vertically, and consist of flat strips with circular indentations to increase the adhesion. They are fixed in position by bending round the longitudinal reinforcement, the web of the latter being pierced where necessary, and the stirrups passed through and bent round one half of the bar. The stirrups are spaced apart at the centre of the beam, at distances equalling about the height of the centre of gravity of the compression area above the centre of gravity of the reinforcement, the stirrups being more closely spaced nearer the supports. Bonders of the same material are used as shown, to improve the connection of the beam with the floor slab.

The columns in this system are reinforced by round bars, hooped by rings of round iron, made on blocks to suit the overall dimensions of the bars.

The floor slabs are reinforced in both directions by round bars.

"COIGNET" SYSTEM.

In the "Coignet" system shewn in Fig. 22, top reinforcement is used, and the stirrups consist of round bars of small diameter forming loops connecting the upper and lower reinforcement, the distance apart being varied as in the before mentioned systems to suit the increasing shearing forces near the supports. Floor slabs are constructed as in the "Monier" system by two sets of bars crossing each other at right angles near the lower

surface, and when the loading requires it top reinforcement and vertical stirrups are used as in the case of beams.

The columns in this system are reinforced by longitudinal bars spirally wound with bars of smaller diameter at 3 to 4ins. pitch, annealed wire being used at all intersections.

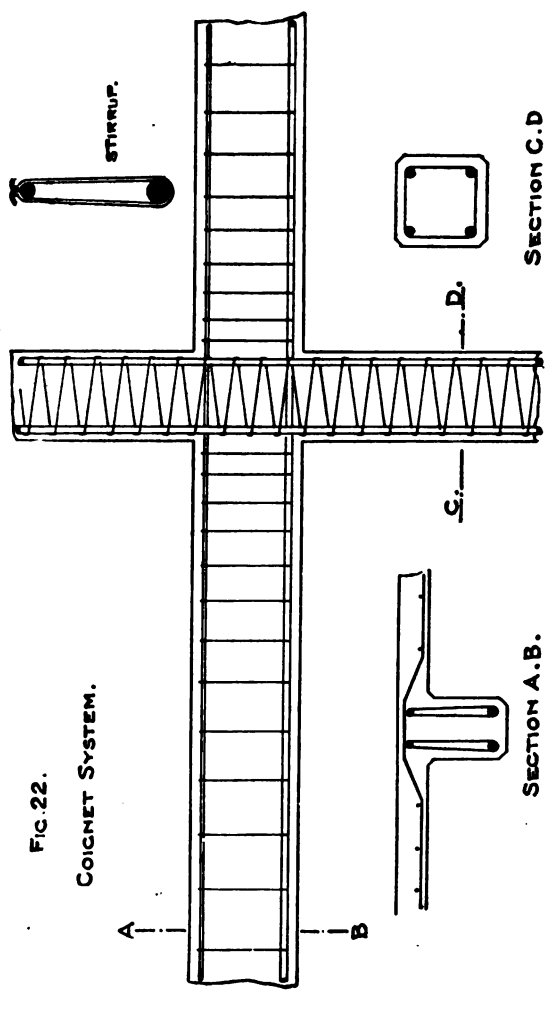


FIG. 22.
COIGNET SYSTEM.

"KAHN" SYSTEM.

In the "Kahn" system, Fig. 23, the longitudinal reinforcement consists of bars of special section as shewn, which resemble a square bar with two projecting wings. These wings are sheared longitudinally and bent up at an angle of 45° thus forming fixed stirrups to resist the shearing forces in the case of beams and slabs. Where top reinforcement is required similar bars inverted are used.

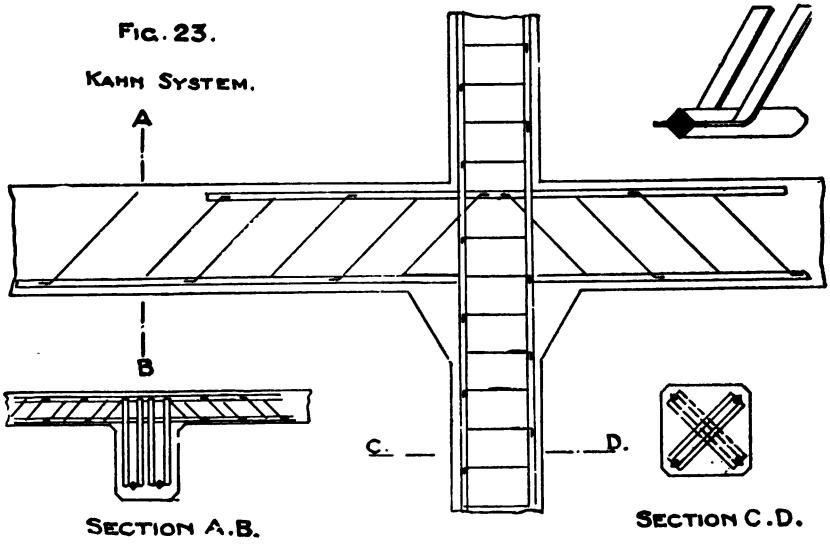


FIG. 23.
KAHN SYSTEM.

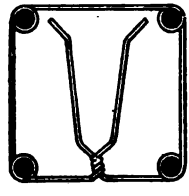
In the case of columns the wings are bent to an angle of 90°, or inclined downwards and arranged so that they pass through the centre of the column. The columns are spirally wound at the bottom with round bars of small diameter.

"SURTEES" SYSTEM.

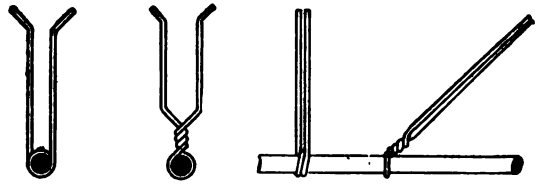
Another system, recently introduced, is the invention of Mr. R. T. Surtees, of Newton-le-Willows, and details of the hoops for columns and stirrups for beams are shown in Fig. 24.

The hoops for columns are bent round the longitudinal reinforcement to keep this in position, and the ends are left long and twisted to act as a tie through the centre of the column.

The forms of stirrup used for beams and slabs are also shewn and can be used either as vertical or inclined stirrups.



COLUMN HOOP



STIRRUPS.

Fig. 24.

The stirrups are also used in the construction of walls, etc., as in the "Hennebique" system.

"JOHNSON" SYSTEM.

In the "Johnson" system, which is used in America, and is now being introduced into this country, the reinforcement for beams consists of wire lattice with a rectangular or diamond mesh bent up to form a trough. The side portions resisting the shearing forces, whilst the longitudinal rods are increased in size at the bottom to resist the tensile strains.

The columns are reinforced by vertical rods which are spirally interlaced with rods of smaller diameter, thus forming a lattice with a spiral mesh. Wire lattice with a rectangular mesh is used for the reinforcement of the floor slabs.

BARS OF SPECIAL SECTION.

Bars of special section to prevent the slipping of the concrete are frequently used in America, especially when high tension steel is used, and the "Johnson" indented bar, which consists of a square bar with square indentations on alternate faces is also in use in this country.

Another form is a square bar twisted, and bars on which are formed projections or studs are also in use.

ARCHES.

Concrete, like brickwork and masonry, being weak in tension, arches of plain concrete are designed so that the line of resistance falls approximately within the middle third, and thus tension is not set up at any point. By the use of proper reinforcement the arch can be designed to resist the tensile strains set up by any system of loading, and the thickness of the arch can therefore be greatly reduced.

Reinforced concrete arches are either made fixed at the springings as in the case of ordinary arches of brick and stone or are made hinged at the springings and crown.

The latter method is now frequently adopted, it being possible to obtain the position of the line of resistance more certainly as this must at the springing and centre pass through the centre of the hinge for all conditions of load.

The hinges also allow the arch to adjust itself to any settlement due to the centring, or to the arch taking its bearings when the centring is removed and to the variations of temperature or slight settlement of the abutments, thus avoiding the cracks which would arise from the above causes. Arches

should be reinforced both at the intrados and the extrados, and when a fixed arch is used, the reinforcement should be carried well down and anchored into the abutments.

The reinforcement of concrete arches may be carried out by a network of rods as in the "Monier" and other similar systems, but the reinforcement is frequently arranged to resist shearing forces by the use of stirrups as in the "Hennebique" system or as in the "Melan" system when the reinforcement takes the form of top and bottom flanges connected by a lattice web as in the case of an ordinary steel arch.

OTHER APPLICATIONS.

Reinforced concrete is also used for the construction of tanks. These are usually made circular in form and are reinforced by rods forming rings or spirals in the centre of the wall with vertical rods placed inside of these.

The whole of the tension should be taken by the reinforcement, the concrete merely serving to make the structure watertight, and the stress in the steel should generally not exceed five tons per square inch, so that no cracks may be formed in the concrete.

The concrete is usually faced on the inner surface with 1in. thickness of cement and sand in equal proportions. A stand pipe 20ft. diameter and 50ft. high has recently been erected at Boston, U.S.A., of reinforced concrete, with walls 8in. thick at top and 6in. at bottom, and is stated to be most satisfactory.

Reinforced concrete chimneys are constructed in a similar manner to tanks, and the material has also been applied advantageously to the construction of retaining walls, coal bins, culverts, pipes, and many other structures. Piles of reinforced concrete are now largely and increasingly used for foundation work in bad ground and for piers and jetties. They are constructed in a similar manner to columns, the

bottoms being fitted with a shoe, as is done for timber piles, and they can then be driven in the ordinary manner. The top is fitted with a loose cast-iron cap, with a sawdust bag between the top of the pile and cap, so that the head of the pile may not be crushed or broken by the blows of the monkey. If the piles are for use in ground where the water jet can be used for sinking, they can be fitted with a pipe, cast into the concrete, and carried to the point of the shoe, through which the water jet can be applied. Their advantage over timber piles is that they do not decay, and in the case of marine work are not destroyed by the teredo and other destructive forms of life.

The material can also be advantageously used in the case of buildings on bad ground by forming the whole area of the foundation into a raft properly stiffened by beams or ribs to take the weights of the columns and walls, and thus distributing the whole of the load over the whole area covered.

Buildings of reinforced concrete are usually constructed as a complete frame, the sides being stiffened with columns and girders, and the walls being simply slabs filling in the spaces between, which need not be more than 4in. in thickness. Brick walls can also be used instead of concrete for the filling in between wall pillars, as is done in the case of a steel frame building.

Reinforced concrete, when properly used, is a valuable material of construction, and although failures have occurred, these have been proved to be due in some cases to faulty design, but in most instances to the work being badly carried out.

In San Francisco, at the time of the earthquake, the material had only been used in a few structures, but in all cases stood the test satisfactorily.

Its chief advantages are its monolithic character, its durability (and therefore small cost of maintenance), the ease

with which it can be moulded to suit any position, and its fire-proof qualities.

It should, however, be mentioned that when a fire-proof structure is required limestone should not be used, and the aggregate should be broken small in all cases to pass a $\frac{3}{4}$in. mesh. As with a long-sustained fire, the exposed concrete parts with its water of crystallization, and is thus weakened, additional concrete above that required for strength should also be allowed.

No material requires more careful design and superintendence during construction than reinforced concrete, and if this is not given, the safety of the whole structure is endangered.

The forms, or moulds, must be rigidly constructed and so strutted and supported as to be strong enough to carry the weight of the material without deflection or deformation, and generally speaking, should not be removed before the expiration of 28 days, so that initial strains may not be set up whilst the concrete is setting.

All the materials, including the water, must be clean, and if any doubt exists as to the cleanliness of the sand or stone, they should be washed before using. Coke breeze is not suitable, owing to the possibility of it containing sulphur which would attack the steel and it moreover only makes a comparatively weak and porous concrete.

Care must be taken with the gauging to see that all the constituents are mixed in their proper proportions and in this connection, the effect of proper mixing is shewn by the diagram given in Fig. 25, shewing the increase in strength of concrete made of Thames gravel when the excess sand is eliminated and the flints broken, over the strength when the ballast is used as received, for which information the author is indebted to Mr. E. P. Wells.

The concreting should not be carried out during frost, and when the weather is hot should be protected by covering with bags or other means, and be kept wet so as not to set too quickly.

The work should as far as possible be carried out evenly over the whole structure and when it is necessary to make a connection with work set or partially set, the surface should be thoroughly cleaned and wetted, and covered with a layer of cement mortar before the fresh concrete is deposited.

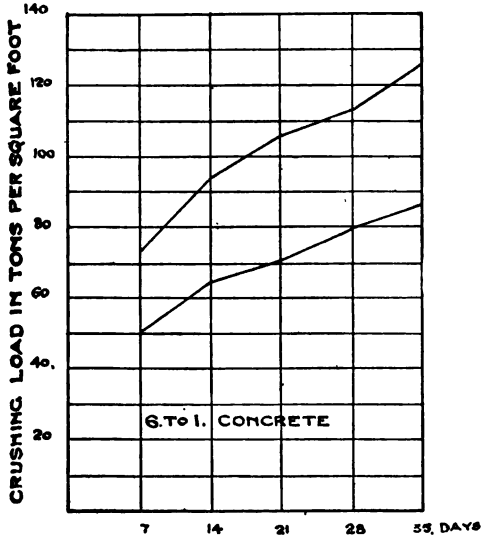


Fig. 25.

The class of concrete required is very different to that necessary in ordinary building work, and close attention must be paid to every operation to ensure a satisfactory result.

The reinforcement must be of course free from paint, grease and loose scale, and care must be taken to ensure that it occupies its proper position and that the arrangement adopted permits of the proper manipulation of the concrete. It has

been found that the best adhesion is obtained when the steelwork is free from scale and slightly rusted.

Whilst details of relative cost are of course difficult to obtain and naturally vary according to the locality, it may be stated that in most cases, its cost will compare well with that of other forms of construction, whilst its advantages render it in many cases a most desirable material and well worthy of consideration.

Reinforced concrete construction has up to now been mainly in the hands of the patentees of the various systems. The main principles are not however patentable and the patents in many cases only apply to some particular detail. The subject is still comparatively new and the details of the reinforcement are sure to be greatly developed as reinforced concrete becomes more used and better understood. It is probable that considerable progress will take place in the direction of building up the main reinforcement as a self-supporting lattice construction, strong enough to carry itself, the concrete and forms whilst the work is being constructed, and the external load when the concrete is added.

It has been thought that views of one or two typical structures of reinforced concrete construction in this Country would be of interest and the author wishes to thank the President, Mr. W. H. Hunter, M.Inst.,C.E. for the loan of photographs; and the Editor of "Concrete and Constructional Engineering" for the loan of blocks from which the illustrations have been prepared.

DISCUSSION.

THE PRESIDENT (Mr. W. Henry Hunter) in opening the discussion said the paper was most interesting and instructive, and he would suggest to those whose minds were bounded by

their shop walls—and he was speaking of that of which he had had some considerable practical experience—that in building new shops they would, in days to come when they had grown wiser, find that they could build at considerably less cost, better structures in re-inforced concrete instead of in steel, iron and brickwork.

The structure, however, would not be "fireproof," although Mr. Allott had claimed that faculty for re-inforced concrete. It was a claim which could not be substantiated for any material whatever, as no material dealt with at the present day was "fireproof," and that for a very simple reason.

If they reflected sufficiently to trace the origin of any material sufficiently far back, they would find that the material began in a gaseous condition, trace anything far enough back and they would find it was gas. The difference between gaseous condition, liquid condition and solid condition was purely a matter of temperature; any material known, if made sufficiently hot, would become liquid, and if they were able to raise the temperature to a sufficient extent, it would become gaseous. Sufficient was not yet known of the many mysterious radio-active materials to speak definitely regarding them, but we could speak with the greatest confidence for the materials now dealt with. Therefore, there was nothing "fireproof," it depended entirely upon the temperature and the time to which the material was exposed to that temperature.

He (Mr. Hunter) was a member of the Fire Prevention Committee of this Country, and they had decided to abandon the term "fireproof," and substitute "fire-resisting."

Although there was nothing "fireproof" a ferro concrete building would resist fire of a greater temperature, and for a much longer time than any other material; that had been

proved in the great Baltimore fire, and still more recently in the Toronto fire and the conflagration which followed the disastrous earthquake at San Francisco.

With respect to the material itself, Mr. Allott had properly begun with a reference to M. Monier. It was regrettable that whilst men like Hennebique and others had made enormous fortunes out of ferro concrete, the man who really introduced it was to-day in such disastrous circumstances that recently an appeal was made to users of the material and to those interested in it, to subscribe to a little fund to keep him from absolute destitution in his closing days.

M. Monier was originally a gardener, a man of great power of mind—a natural genius—in his gardening operations he wanted large pots for his plants, trees, shrubs, and found great difficulty in getting them because the ordinary pots cracked and broke. He then made some pots of concrete, but found the growth of the plants burst the concrete also; and he then conceived the idea, which was a stroke of genius, of coiling steel wire round the pots; this steel wire grew bigger and bigger, and he found after he had let it set long enough that no tree which he put in could burst his ferro concrete pots.

That was the real origin of ferro concrete construction.

In ferro concrete construction there were undoubtedly certain difficulties, the special one being that it was a structure in which men must think of what they were doing. To illustrate this he wished to refer them to the photograph, Fig. 1, of the transit sheds (not warehouses as they were often wrongly described) at the Manchester Ship Canal Docks. These sheds were of sufficiently large dimensions to make the construction difficult, being 425 feet long and 101 feet wide. When the contractors began the work he (Mr. Hunter) at the very outset had some little trouble with their Manager in

connection with the floor of the first shed; this man began the construction running fore and aft, *i.e.* lengthways of the shed, and he (Mr. Hunter) interposed and objected as he thought it was perfectly clear that the construction should be transverse, *i.e.* across the shed. Five of the bays were in, and the contractors' man said he thought that was the best way, and in his large experience he had never had the slightest trouble and difficulty with it. However, an alteration was made in the system of construction, and the work proceeded on what seemed to him (Mr. Hunter) to be the proper lines.

It was a remarkable fact that throughout all those acres of floors, 22 acres of ferro concrete floors, there was only one single place where the floors cracked, and that was where the contractors man had constructed it in the way he considered to be a proper one.

It was absolutely necessary in ferro concrete construction that the walls should be tied together; there would be difficulties in any case, especially in respect of cracks in the outer walls, and he did not quite see how that was going to be got over. It was not possible to construct a building over 425ft. long of any material without having expansion and contraction. With ferro concrete in which there were no joints, there was just as much expansion and contraction as with brickwork walls, but with concrete walls you saw what was taking place. If the walls were built of solid masses of ferro concrete, there would almost inevitably be trouble with cracks, and if it was desired not to see the cracks it was better to build the columns, girders and floors of ferro concrete, and then case them in comparatively thin brick walls in which the cracks would not shew in the manner in which they shewed in ferro concrete.

The advantage of ferro concrete in the construction of

buildings of any length was the readiness in which they could build and reliably form the beams as continuous, *i.e.*, treat them as continuous girders. The point of "contra flexure" within limits could be readily determined, and at that point of "contra flexure" they made the slope line of the upper two re-inforcing beams carried over the top of the column, and then brought down to the centre. They made that centre of inclined plane of re-inforcement coincide with the point of "contra flexure," and it was then possible to lighten the material or girders, and thus reduce the cost in steel.

Although the author had put it carefully and in guarded terms as to the advantages of cost, he (Mr. Hunter) was quite certain that it was possible to build very much cheaper in the way he was suggesting.

There was a great difference of opinion as to the degree of moisture, the quantity of water which should be added to ferro concrete work. Personally he agreed with Mr. Allott that it was better that concrete should be put in fairly well wet if it was carefully punned into place; if not, any concrete put in with a considerable mass of water such as usually put in large foundations, walls and so forth, would inevitably be very porous, because owing to the chemical combination and ease with which the oxygen of the water combined with the carbonic gas in the lime, there was likely to be an undue proportion of oxygen in the mixture, with the result that the structure would become more or less honeycombed in texture. If the concrete was made wet it would be more certain of adhesion to the steelwork if it was punned to a sufficient degree to consolidate and bring the excess of water to the surface.

If ordinary care was taken there need be no apprehension

about oxidisation of the steelwork. In this connection he mentioned that two years ago he had occasion to remove, at the entrance to No. 9 dock, a concrete wall that he had himself built in 1892. In that wall there were a number of "bollards" for the mooring of large steamers, and those "bollards" were built of steel frames bolted down, the bolts being 7 or 8ft. in the concrete. No special care was taken with that concrete, there being one part of cement to eight of ballast and broken stone and sand pretty well packed, and cost 10/- to 12/- per cubic yard. On removing the concrete it was found that the red lead put on the bolts in the makers' shops was untouched, and that underneath the red lead the natural bloom of the steel absolutely untouched after 12 years under circumstances of great difficulty.

He mentioned that matter because there had been, and still was much apprehension expressed as to the possibility of the steel withstanding corrosion under water, or exposed to a damp atmosphere, perhaps such as that of Manchester, which had no small proportion of free acid. With ordinary care in construction there was no danger whatever of that occurring.

Mr. BYROM (Bury) (Visitor) said that although he knew something about the puttting in of concrete, he had not had a large experience with ferro concrete. As a matter of general interest he mentioned that he was in South America last year, and called at Calcuana where the docks belonged to the Chilian Government, and they were there putting in sea walls with re-inforced concrete caissons, the work being carried out by a Dutch engineer.

The walls of the caissons were not more than 6in. thick, and were over 60 feet long, and they formed the whole width of the sea wall. They were made on slips like building a ship:

when they were built they were floated down into the water and sunk into position and then filled with concrete, and formed the sea wall. Their weight, he understood, was over 200 tons. Struts were placed across the divisions so that they could stand.

It was most interesting to see the work going on there, and like the President, he could see that there was a great future for ferro concrete in England. He believed it could be done cheaper than brick or stone for warehouses, transit sheds, sea walls and dock walls.

Mr. DANIEL ADAMSON said he looked upon the paper as a very valuable addition to the year's Proceedings, as it gave information upon what was certainly a most important new development in methods for the building of workshops.

The author's statement on page 188 that "the class of concrete required is very different to that necessary in ordinary building work, and close attention must be paid to every operation to ensure a satisfactory result" ought to be printed in especially large type. With ferro concrete the whole construction had to be watched to the end by a competent man; even in making a floor, as the President had pointed out, somebody must watch it who was going to be responsible for it in days to come, to see that the builders were using some judgment in carrying out the operations.

He thought the author might have referred more fully to chimneys, which were very important examples of the ferro concrete method of construction. With brick chimneys they were told there was a considerable amount of infiltration of air. The President had suggested a very possible cause of infiltration, viz: in the number of cracks to which brick work is subject, but to which ferro concrete would not be.

Further, an advantage of ferro concrete was the reduced weight with a concrete chimney as compared to a brick chimney. A considerable proportion of the cost of building a chimney was for the foundations below the ground surface, these having to be very large to carry the great weight above it, and in many situations it was impossible to build the type of chimney desired owing to the ground not being suitable to carry the great weight. For instance, on the banks of the Thames, where the ground is very soft, there were many large works, and at one in particular which he was acquainted with, they were not able to build a large chimney, and got over the difficulty originally by building a number of small ones. Recently, however, they had put in a large concrete chimney, with perfectly satisfactory results. This chimney is 250ft. high above ground, 20ft. diameter inside, 12in. thick for the first 84ft. and 8in. thick above that. There is a 5in. lining 84ft. high, separated from the main wall by a 4in. air space. This chimney weighs about 1,200 tons, while a brick chimney of corresponding diameter and height would weigh about 3,000 tons. In watching the building of this chimney the fact struck him that a responsible engineer had continually to be on the spot to see that every mixing of concrete was promptly applied, and also that the sectional area of every rod was correct, and that the rod was put in such a place that the calculations could be depended on; it was very easy to get the rods displaced or one mixing of concrete wrong, and thus ruin the chimney, as had recently been shown in the United States, where a large chimney had fallen. The explanation of that accident was that some carelessness took place in the construction half way up, resulting in a bad mixing of concrete being put in.

Calculations had been given by Mr. Allott for the main

rods of ferro concrete columns, and he had also referred to some extent to the hoops used in the columns, but said nothing about the sizes of such hoops. The distance apart for the main rods was given, and he (Mr. Adamson) understood that the diameter of the rods forming the hoops should be from one-thirtieth to one-fiftieth of the distance apart.

In connection with the use of expanded metal, it would be well to caution users against depending upon such material for re-inforcing heavily loaded floors, as one authority—of course there were several—who had used concrete, explained that expanded metal might not be a suitable re-inforcement for important positions. It was, however, as Mr. Allott mentioned, very suitable for walls and minor operations.

Mr. J. P. BEDSON prefaced his remarks by mentioning that he was speaking more in reference to the mixing of concrete in iron and steel works, where they usually took bricks, of which there were a good many always at hand.

Unfortunately, nowadays a large quantity of silica bricks were used, and, although it was perhaps not generally known, silica was the greatest enemy one could imagine to concrete. In this connection he had recently put in a foundation for a small rolling mill, and found that a very small proportion of silica bricks mixed up as ordinary bricks got in to the concrete, and immediately it set it then began to disintegrate. In the foundation in question, a block of concrete about 12ft. cube, disintegrated and burst as though a charge of dynamite had been put in the centre, it all broke away and lifted up five or six inches. The whole of the concrete had to be taken up, not an ounce being left, as the silica had ruined it altogether.

He learned that fact from experience; but found out afterwards that at Dowlais Iron Works they had done some work there and had cautioned the contractor not to put a single piece of silica brick, even the size of a nut, in with the concrete.

As regards re-inforced concrete, before this was very well known, he had occasion to put down a rolling mill engine on marshy land, and the question lay between piling and concrete. He elected to make a huge plate of concrete, and tied it together with old rails and rubbish longitudinally and transversely. That was in 1893, and the thing had stood perfectly from that time and had never cracked or moved.

Mr. A. W. STOREY stated that he did not agree with the use of wire netting for the re-inforcement, the tension of every wire in wire netting was uneven, and it appealed to him very strongly that each wire should take its own strain in the support of buildings, walls, or floors, as the case might be. Also, in floors or arches that had only two supports, it was better to keep the wires the narrow way, *i.e.*, as far apart as possible, just sufficient to keep the wires in position.

Mr. WILLIAM INGHAM said that whatever diffidence engineers might have in accepting ferro concrete at present, he thought it would be agreed that the paper was a very interesting one, and that Mr. Allott had gone into the matter in a very careful and scientific manner. The dominant feeling in his (Mr. Ingham's) mind was that there was a great amount of uncertainty about the material; Mr. Allott had been very candid in that respect, inasmuch as he mentioned that no material requires more careful design and construction.

The elastic limit had been very properly referred to as being the governing quantity. To him (Mr. Ingham) it seemed that

this was one of the weak points of ferro concrete. It was pointed out that when the modulus of elasticity drops suddenly it alters the position of the neutral axis, and that, to a great extent, vitiated a great many of the calculations and formulas. There was a difference of about 50% in the ratios between E_c and E_s, *i.e.* the modulus of elasticity of concrete and of steel, This introduced an element of uncertainty which made it very unreliable, and added to the doubtfulness of the material itself it made one somewhat chary of adopting it for structures subjected to strains.

Mr. SAM BOSWELL said he would like to have a clear idea as to the cost of ferro concrete construction. In connection with this point, some little time ago when at Liege he visited with other members of the Association several works where ferro concrete had been used; the appearance of that work was very good, but did not appear as if it could be done at anything like the cost of the ordinary structure.

One of the bridges, 180ft span, over a deviation of the river at Liege, was also constructed of ferro concrete, and when tramcars were on the bridge there was practically an absence of vibration. He had been informed, however, that this bridge had been found unreliable and had been rebuilt.

On the historical side of the question, he mentioned that the first application of ferro concrete which he saw was in Warwickshire, where a firm of cement makers in the late seventies or early eighties were making stable fittings and other articles of it, they used woven wire, but for the same reason as mentioned by Mr. Allott, had to cease that method of manufacture because the wire was not sufficiently reliable, and a better quality of wire-work would be too expensive. At that time expanded metal was unknown.

The first concrete chimney he was acquainted with was also built about the same time, at Goodbody's, Clara Mill, in Ireland. It cost a great amount of money, but not so much as if bricks or stone had been used, as these would have required carting a great distance to the mill. The chimney was planned and built throughout by Mr. Robert Goodbody, one of the proprietors of the Jute Spinning Factory, and not a single skilled workman was employed in its construction. The chimney was 160ft. (from ground level) high, and although they had then no knowledge of ferro concrete scrap iron was put in. That chimney was to-day a fine example of a concrete chimney built by an amateur.

Again, in Liverpool, in the Scotland Road district, some houses were built many years ago of ferro concrete, made from the burnt refuse from the Destructor; he believed the outsides of the houses were made all in one piece, but after making the sides, trouble was experienced in getting them to their places.

He had received a letter from Mr. Robert Goodbody, Clara, Ireland, as follows:

"In reply to your letter of the 8th, the concrete chimney is 160ft. high from ground; 8ft. diameter inside all through; foundation, 12ft. thick by 35ft. diameter; external diameter at top 10ft. 6in., bottom, 18ft. Commenced to build August, 1883, was working in February, 1884. Mixture: one cement, three sand, with about five parts large stones mixed when filling. It was the first concrete chimney in Great Britain. Took 100 tons of cement for chimney, fences and economisers. We have since put in a second economiser. We are using Perrett's furnaces and forced draught."

Yours truly,

ROBERT GOODBODY.

Mr. MATTHEW INGRAM mentioned in reference to Mr. Bedson's remarks on the use of silica for the mixing of concrete, that 30 years ago in connection with an important Manchester building, he (Mr. Ingram) insisted that the concrete for the floors in the corridors should be made of a silicate material which was obtained from the Manchester or Salford Gas Works broken retorts and broken firebricks. This concrete floor is still as strong as when originally put in.

Similar concrete of the same material was also used a year after for the corridors of the Proctor Gymnasium at the Manchester Grammar School, and that also was now very little worse for wear.

Concrete, as Mr. Allott mentioned, was not a new material; dwellings had been built of it in Whalley Range, Manchester, 20 or thirty years ago. He (Mr. Ingram) inspected those buildings at that time, and a report was published by "The British Architect" at the time, and now, at the present day, wished to repeat his report that so far as stability, strength and economy of construction were concerned, concrete was all that could be desired. Like everything else, it required to be used in conjunction with common sense. It would be remembered that some years ago concrete became fashionable with the landed interest for the building of cottages for their workmen, but the construction of those buildings was carried out by inexperienced men, with the result, generally speaking, that they were a failure, and concrete buildings which should be almost universally used where economy was the main factor, had been condemned.

He thought there was such a future for concrete construction, either re-inforced or otherwise, that its general economy would commend itself for the use of engineers, and he hoped it would be more often used in the future than it had been in the past

Mr. BEDSON further remarked in reference to the "silicate" referred to by Mr. Ingram, that there was a difference between a "silicate" brick made from Stourbridge clay which was used for making retorts. They were two different articles entirely. "Silica" was a mineral of a very different character, and has a higher fire resisting quality; it cannot be moulded into anything but bricks, and cannot be made into a fire tube or a gas retort, or anything of that character. At the time the galleries were put in at the Manchester Grammar School he did not think there was any firm in Manchester using "silica" brick except Johnson's, of Bradford, and Ashbury's Carriage Works, and probably even Johnson's were not using "silica" bricks.

Mr. W. INGHAM said he would like to add a few words about "silica" and "silicates." A "silica" brick was not a a "silicate" brick. "Silica" bricks could be used with advantage so long as they were kept continuously hot, such as in gas retorts, but once they cooled down they began to crumble. He thought the "silica" bricks Mr. Bedson had referred to had been highly heated and had got to the crumbling stage.

The PRESIDENT (Mr. W. Henry Hunter) stated in respect to the concrete chimney referred to by Mr. Boswell, that he (Mr. Hunter) was concerned in the construction of the first concrete chimney in this country, which was built at the Chain and Anchor Works of the River Wear Commissioners, at Sunderland, in the early part of 1870, which was, therefore, about ten years earlier than the chimney which Mr. Boswell had believed to be the first built in England. That chimney was still standing, and was a very good and wholesome structure.

Mr. H. N. ALLOTT, in replying to the various speakers, said he only used the term "fireproof" as a relative term; he quite agreed with the President that it would be better expressed as "fire-resisting." He did not think any sensible man claimed reinforced concrete as suitable for everything, but in many cases it was probably the best and cheapest material that could be used.

Mr. Adamson had mentioned the difficulty of arranging and keeping in position the reinforcement. He (Mr. Allott) did not think there was any difficulty so long as proper care was taken; it did not require any skilled-labour as far as he could see except that the contractor should have a competent foreman, and the employer a competent Clerk of Works to keep his eye on the foreman.

Mr. Adamson had mentioned the short reference to reinforced concrete chimneys; but of course it would be recognised that the Paper could not deal in detail with all the different matters in connection with the use of concrete. In many cases there would no doubt be a considerable saving by building a reinforced concrete chimney. The first reinforced concrete chimney in this country had just been erected in London, it was 300 feet high, but there was nothing special about it and he did not think any further details without drawings would elucidate matters.

The chimney failure in the States which had been mentioned, was due to a failure at the top of the inner lining, this lining being a protection against fire. He understood that the forms for making the necessary offset at this point were not in position and after spending some hours in making these right the concrete which had been mixed for same in the morning was not used until the afternoon.

With regard to expanded metal, this was very satisfactory for floor slabs, but he would not recommend it for columns or beams. Mr. Storey had referred to wire netting for the reinforcement. If this was properly made to act as the tension reinforcement,

he (Mr. Allott) did not think there would be any difficulty; the bars would do all their own work, but if the high tension wire was objected to annealed wire could be used.

Mr. A. W. Storey interposed with the remark that he did not object to the use of wire netting, but he thought the Author's description was wrong, it should have been termed "wire lattice." The sample (shown to the meeting) was termed "wire lattice," but "wire netting" was hexagon mesh made on machine.

Mr. Allott continuing, said that Mr. Ingham had referred to the uncertainty of the whole question. Of course, as stated in the Paper reinforced concrete was more or less a new material and there was still a good deal to be learned about it. Regarding the modulus of elasticity of concrete, he thought it would be quite safe for ordinary purposes if this was taken at one-twelfth that of steel.

Respecting the cost, he did not see how some of the structures put up on the Continent could be economical because they seemed to apply it to purposes for which we should not consider it suitable. Speaking generally, with reinforced concrete, even allowing for payment of royalty if a patented system was used, a considerable saving could be made. Mr. Platt, the Borough Engineer of Rochdale, had informed him that the saving on six bridges constructed to meet special circumstances amounted to about 20%, even after paying a royalty of 12% to the patentee.

The houses built at Liverpool were not a success; the idea of making a standard house and building up the sides in pieces was not economical or satisfactory in any way, and was not the proper method of building reinforced concrete structures.

The size of hoops in the columns vary a good deal with the different systems, but generally speaking about $\frac{5}{16}$in. or $\frac{3}{8}$in. diameter rod was the largest size used, and in the case of spiral winding a very much smaller size was used. In the "Hennebique" system links or hoops of small diameter were used.

1 Plate follows illustrating this Paper.

Fig. 5.—Cement Warehouse (interior), London.

UNIV. OF MICH.

MARINE GAS PROPULSION

IN RELATION TO

IMPERIAL COMMERCE AND DEFENCE.

READ SATURDAY, 26TH JANUARY, 1907,

BY

Mr. A. VENNELL COSTER, M.I.Mech.E.,

(MANCHESTER.)

Marine propulsion by gas engines is rapidly coming to the front, and many of our leading engineers are devoting their attention to it. It is, therefore, not out of place that Manchester, now one of the largest ports in the United Kingdom, should also take up the consideration of this subject. Having had 15 years with the marine steam engine, 3 years at sea with the Peninsular & Oriental Co., and following this, 11 years with the internal combustion engine in connection with Messrs. Crossley Bros., of this city, I trust you will consider that I am not presuming upon you, when dealing with such a drastic departure from the known and proved lines of marine engineering as the title of my paper to-night suggests.

It has been said that the impossibilities of one generation become the possibilities of the next, and it would not be inopportune to recall the legend in connection with the Russell controversy of over half a century ago, as to the possibility of driving ships across the Atlantic by steam power, when Mr. Ladener threatened jocularly to "eat" the boilers of the first steamship that could accomplish it. I venture to think that there may be gentlemen present to-night, who would be willing to treat the subject of to-night's discussion in the same airy spirit. This paper will attempt to convert them to a belief, not only in the

possibility, but the probability, of our largest ocean going vessels and battle-ships being, in the not very distant future, driven by the gas engine and gas producer. Also, was not the introduction of the marine steam turbine attended by a general feeling of scepticism and prejudice by all engineers who were supposed to know? But in spite of its inherent defects for marine purposes, the steam turbine is not only an accomplished fact, but a magnificent success, largely due to the extraordinary perseverance and mechanical skill of its inventor, the Hon. C. A. Parsons. It has proved its superiority over the best reciprocating steam engine at full speed in steam consumption, and while the area occupied by the turbines, and their weight, is practically the same as for reciprocating engines, the space and weight of the boilers is quite 10% less.

HEAT BALANCE SHEETS COMPARED.

In order to estimate the relative merits of gas reciprocating, engines, steam turbines, and steam reciprocating engines for marine purposes, the author has prepared Diagrams, Fig. 1, Fig. 2 and Fig. 3, which are based on the best averages now in practice, and with fuel best suited to boiler or producer. These figures have been submitted to such eminent authorities as the Hon. C. A. Parsons, Captain H. Riall Sankey, R.E., Mr. A. Basil Wilson, M.Inst.C.E., and compared with data given by Mr. J. E. Thornycroft, which substantially agree with them.

In Diagram Fig. I. of marine gas engines the heat efficiency of the gas producer is taken at 80%. This is a very moderate figure, as there are gas producers at work utilising 90% of the total heat of the coal supplied. This is also corroborated by Mr. J. E. Thornycroft who quotes 90% for suction plant efficiency in his paper on "Gas Engines for Ship Propulsion." *

* See proceedings Institute of Naval Architects, 1906.

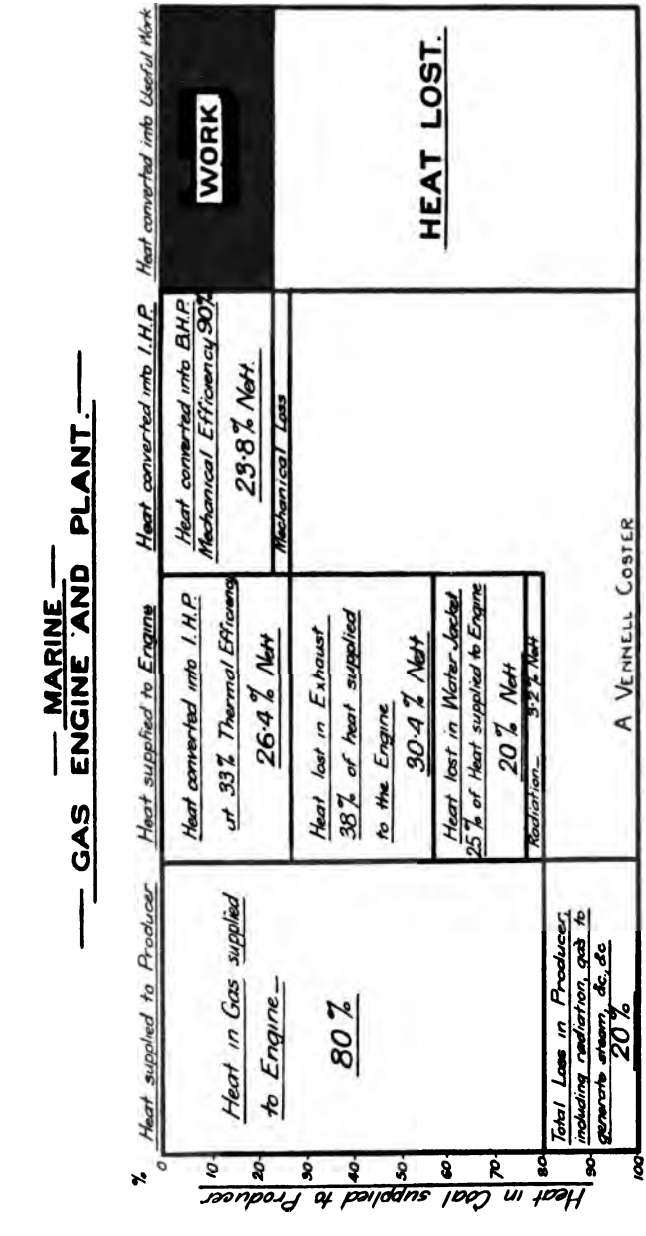

MARINE
GAS ENGINE AND PLANT.
Heat supplied to Producer
Heat supplied to Engine
Heat converted into I.H.P.
Heat converted into Useful Work
Heat converted into B.H.P. Mechanical Efficiency 90%
23·8 % Neh.
WORK
Mechanical Loss
Heat converted into I.H.P. at 33% Thermal Efficiency
26·4 % Neh
Heat lost in Exhaust 38% of heat supplied to the Engine
30·4 % Neh
Heat lost in Water Jacket 25% of Heat supplied to Engine
20 % Neh
Radiation 3·2 % Neh
HEAT LOST.
Heat in Gas supplied to Engine
80 %
Total Loss in Producer, including radiation, gas to generate steam, &c. &c
20 %
A VENNELL COSTER
% Heat in Coal supplied to Producer
0
10
20
30
40
50
60
70
80
90
100

Fig. 1.

In Figs. 2. and 3. the usual marine cylindrical boiler, with internal fire grate and return tubes is considered. Water tube boilers have a much lower heat efficiency, their chief claim being not heat efficiency, but quick steam raising properties. The late Mr. Bryan Donkin gave the average heat efficiency of marine steam boilers at 66·7%; Mr. Basil Wilson, of Belfast, states that "it seldom exceeds 65%, though on trial trips it may reach 70%; cleaning fires and other losses bring it down, the heat efficiency being the percentage of heat units in the coal, added to the feed water and delivered as steam."

I am aware that land boilers with modern heat saving appliances reach a thermal efficiency of 80% and over, but for marine practice 70% as shown, is the best obtainable.

The efficiency on IHP for gas engines is taken as 33%, (Fig. I.) giving a brake thermal efficiency of about 30% for vertical type engines. The thermal efficiency of the whole plant working out at 23·8%.

STEAM TURBINE EFFICIENCY

The thermal efficiency of steam turbines, shown on Fig. 2., on IHP is an unknown quantity, as is also its mechanical efficiency. From actual experiments taken with two vessels (in duplicate, as far as form and wet surface are concerned, one driven by turbines, the other by twin screws, at the same speed, including all necessary auxiliary machinery, and working between the same temperature ranges,) the IHP thermal efficiency of the turbine may be taken as 20%, with a vacuum of 27ins. The mechanical efficiency is taken as 93%. As far as is at present known steam turbines fall off more rapidly in thermal efficiency than reciprocating steam engines.

RECIPROCATING STEAM ENGINE EFFICIENCY.

In Fig. 3, for marine reciprocating steam engines, the efficiency on IHP is given as 17%, and mechanical efficiency as

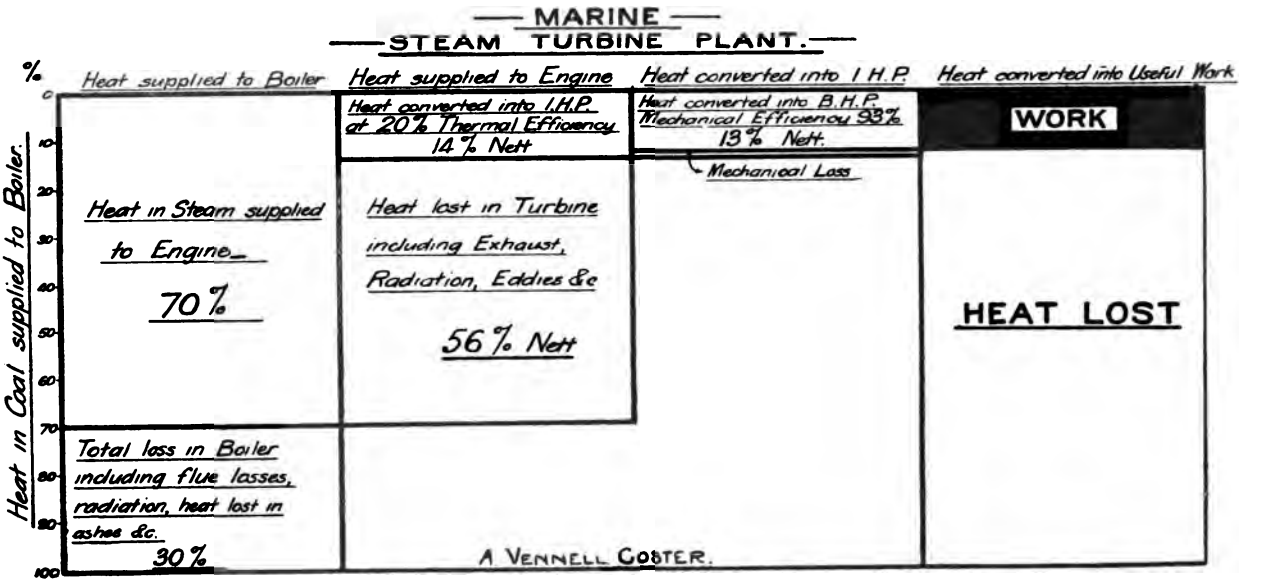

MARINE
STEAM TURBINE PLANT.
%
Heat supplied to Boiler
Heat supplied to Engine
Heat converted into I.H.P.
Heat converted into Useful Work
Heat converted into I.H.P. at 20% Thermal Efficiency 14% Nett
Heat converted into B.H.P. Mechanical Efficiency 93% 13% Nett.
WORK
Mechanical Loss
Heat in Steam supplied to Engine 70%
Heat lost in Turbine including Exhaust, Radiation, Eddies &c 56% Nett
HEAT LOST
Total loss in Boiler including flue losses, radiation, heat lost in ashes &c. 30%
Heat in Coal supplied to Boiler.
0
10
20
30
40
50
60
70
80
90
100
A VENNELL COSTER.

Fig. 2.

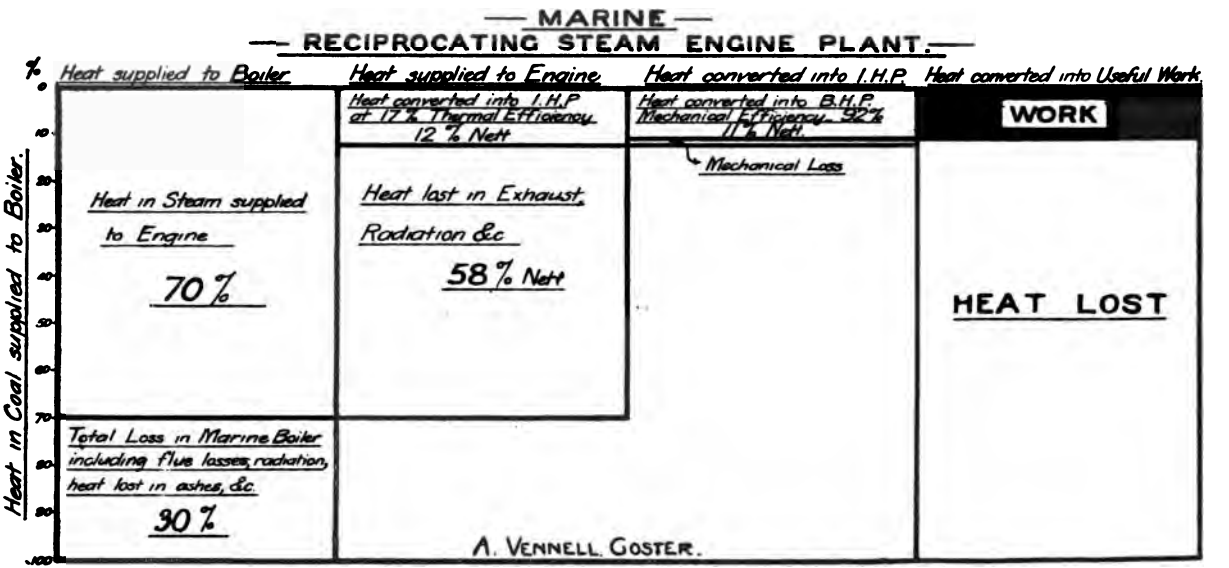

MARINE
RECIPROCATING STEAM ENGINE PLANT.
%
Heat supplied to Boiler
Heat supplied to Engine
Heat converted into I.H.P.
Heat converted into Useful Work.
Heat converted into I.H.P at 17% Thermal Efficiency 12 % Nett
Heat converted into B.H.P. Mechanical Efficiency 92% 11% Nett.
WORK
Mechanical Loss
Heat in Steam supplied to Engine
70 %
Heat lost in Exhaust, Radiation &c
58 % Nett
HEAT LOST
Heat in Coal supplied to Boiler.
Total Loss in Marine Boiler including flue losses, radiation, heat lost in ashes, &c.
30 %
A. VENNELL GOSTER.

Fig. 3.

92 %. These results were obtained on the S.S. Iona, under test by the Institute of Mechanical Engineers. As a rough commercial comparison on the basis of these figures, we may safely assume that of the total heat in the coal, the gas engine turns into actual work about twice as much as the best reciprocating engine or steam turbine. The fuel consumption with steam plants is from 1·3 to 1·6 lbs. per IHP, and with gas plants from ·65 to ·8 lbs. per IHP, so that either the bunker room may be reduced 50 %, or the vessel's radius of action increased 100 % in favour of marine gas propulsion.

ADVANTAGES OF THE MARINE GAS ENGINE.

Members present may say, "why attempt to make the life of the marine engineer more difficult and arduous than it already is? The gas engine has more factors in its composition than the steam engine. Why then impose upon the already overtaxed sea engineer, greater burden and responsibility, all for the sake of an increased economy, which may not work out in actual practice?" Well, gentlemen, no one has greater regard for our marine engineers than myself, and this subject is brought forward with the hope of ameliorating some of their hardships. I feel confident, therefore, that if a marine engineer were told that, by the introduction of the gas installation, he would obtain the following advantages, he would be more than satisfied.

(1) The ship driven with half the amount of fuel.

(2) Stand-by losses reduced over 75 %.

(3) Working pressure confined to the engine cylinders.

(4) No boiler tubes or main steam pipes to burst, or furnace crowns to collapse.

(5) No priming in a heavy sea way, or water hammer in pipes and cylinders.

(6) No more difficulties with the firing of boilers in a beam sea. Gas producers may be charged only twice every 24 hours, and the rolling and pitching of the vessel is rather an advantage than otherwise in assisting the fuel down from the charging hoppers.

OBJECTIONS.

But what of the other side of the question, the dangers of gas propulsion? What about the gas leakage and consequent asphyxiation? Well, care must be exercised to see that all pipe joints are tight, and a good system of ventilation in vogue. None of us object to gas works and pipes being fitted up in our towns and houses, with the possible risk of explosion and asphyxiation, for we know that with ordinary precaution there need be no fear. A sea-going vessel, being for the bulk of its time out on the open sea, and in the best of air, need not be a difficult matter to arrange for either automatic or assisted ventilation for both gas plants and engines.

But the difficulties inherent in the gas engine:—what of these? What about variations in gas values, and sticking of valves, causing unreliability of the engines in working? I maintain that the former have been entirely overcome by higher compression and adjustable double electric ignition, so that gases from a calorific value of 80 B.T.U. to 180 B.T.U. (about the best producer gas value,) can be readily and completely burned in the engine cylinders. And as regards valve sticking, with a good system of coke and sawdust scrubbers, and the ample water supply at command, any quality of gas made from the poorest of bituminous coal can be thoroughly washed. With ordinary care this trouble of valve sticking need never occur, if the valves have forced oil lubrication where subject to pressure, and are inspected and cleaned periodically.

But it may be said, "the difficulty with reversing, what about the failure of the compressed air supply for starting and

reversing?" The ship will necessarily be fitted with duplicate air compressing machines, and if both fail, even then it is not so serious a matter as the failure of the boiler feed pumps, to which they are analogous.

But is such an advance as the marine gas engine and producer necessary? Are not our steam turbines and our triple and quadruple vertical steam engines completely satisfactory to meet the rough and tumble of life at sea? These machines with all the latest improvements in construction are still far from perfect, and especially as regards thermal efficiency, as already demonstrated, and although we assume that our coal supplies are sufficient to last for many thousands of years, it is of national importance that we should attempt to waste less as the years go by. In what way can we use them to the best advantage? My contention to-night is that it must be in the greater use of internal combustion engines, whether on land or sea, for in this system for the utilisation of heat, we get the bulk of the heat within the engine cylinder, and are able to turn a much greater proportion of it into work.

While steam engineers are fighting for another decimal point in thermal efficiency, we can, at one bound, get an increased thermal efficiency of close on 100% over and above anything the steam engine, whether reciprocating or turbine type, can accomplish. Is it any wonder that many of our leading firms are already attempting the problem of marine gas propulsion, with the prospect of such an economy in view? But some may say "look at the difficulties experienced with gas engines and plants when on land. Why then transfer these difficulties and add them to the dangers of the sea?" Here again it is easy to be misled. Failure is so soon reported and the many successes forgotten, and I contend that the bulk of the troubles experienced on shore with gas engines and plants are due either to miscalculation or ignorance, and often prejudice, that when we

take into account the phenomenal growth of gas power and the economies it has obtained, it would ill become an Association such as this, to record a general verdict against Marine Gas Propulsion.

As a nation we depend upon our maritime commerce, upon our fleet of cargo boats, as well as upon our Imperial Navy, and it is of vital importance to us that we lead the way in any and every attempt to increase the economy and efficiency of these. By means of gas engines and gas producers we know that it will be possible to increase the radius of action of all vessels from 75% to 100% on the same quantity of coal, and this will mean a great deal. We must advance or other nations who are pressing hard upon us will take the lead in this matter. We cannot afford to stand still. We do not hold the same position in the world as fifty years ago, when a Committee of the House of Commons reported "that the United Kingdom from the natural and acquired advantages possessed by it, would for ages continue to retain the superiority it now enjoys over all other nations; that the industry and power of our people was unequalled, their ingenuity in the continual improvement and production of commodities being without parallel and apparently without limit." The ineffable complacency of this report scarcely accords with the experience we have gained in the interval that has elapsed. As a matter of fact we have in many directions fallen behind other nations, except in the case of our Mercantile Marine, which is to-day 50% of that of the whole world, and in the development and efficiency of which, we are taking, I hope, an active and intelligent interest.

You may know that many influential firms have already applied themselves to this venture, and the results so far have been by no means discouraging. There are still many difficulties to be faced and overcome, but they will be overcome. In this paper my proposal is to put before you such a scheme of

marine gas propulsion, that the most cautious of us would be willing to risk a voyage by its means.

THREE MAIN DIFFICULTIES.

The three main difficulties in our way are:—

1st. The construction of a gas producer able to gasify all grades of bituminous coal.

2nd. A simple method to cleanse the gas from tar, either before the introduction of the fuel into the producer proper; when in the producer; or after the gas has left the producer on its way to the engine.

3rd. Perfect control of the gas propelled vessel in starting, stopping, reversing, and running at all speeds.

Dealing with No 1 and No. 2. If anthracite coal or coke is used these difficulties are entirely avoided, but with a limited supply of anthracite our wisest course is to leave it out of the question altogether. For marine purposes we must deal with the ordinary coal that may be obtained, not only in Wales, but in various parts of the United Kingdom, and the many coalfields scattered about the world. Bituminous coal is cheap compared with either anthracite or coke, and as I have already stated, it is the only possible fuel for marine gas producers. Its thermal value varies from 10,000 to 14,000 B.T.U. per lb., and costs from 6/- to 7/- per ton. For many years gas engines have been driven by bituminous coal gas, and the difficulty has always been to get rid of the condensible hydro-carbons which would fill and clog the valves and gas passages of any engine they were allowed to enter. This problem is one that must be faced rather by our chemists than by our engineers, and many notable firms have already solved the problem, but not in that simple manner that would make the gas plant perfectly suitable for marine purposes. It is reported from several trustworthy sources that a simple solution has been discovered.

Then there is the necessity of dealing with the many grades of bituminous coal, some suitable, many unsuitable. Shipowners would have to insist on a correct analysis being supplied prior to delivery so as to ensure gas producing qualities.

There are also other difficulties within the producer itself, in the behaviour of the coal when heated up. Bituminous coal may be either of the caking or non-caking varieties, and although of very similar composition they behave very differently when under treatment. The non-caking varieties are more suitable for our purpose and make the best gas, whereas the caking coal often leads to the formation of a hollow fire, with the result that the gas produced is of poor quality. It has been proposed to coke the bituminous coal before introducing it into the gas producer, so as to reduce the percentage of hydro-carbons to a minimum and prevent caking in the producer. In these problems there is much for the consideration of the best trained intelligence that we possess.

THE "LORD ANTRIM."

In the cargo vessel, the "Lord Antrim," Plate I., are gas producers in which the upper part of the furnace is worked with a down draught, and the lower part with an up draught, the gas being drawn off at the centre, on the suction principle. The raw fuel is introduced at the top, and is coked as it settles down towards the gas outlet; the hydro-carbon or tarry vapours in the meantime are either destroyed, or converted into fixed gases when passing through the incandescent fuel to outlet. There are primary and secondary hot air supplies, the latter, drawn up from the producer base, is charged with steam vapour, and gas is made on its passage through the coked fuel; the gas afterwards is thoroughly sprayed and finally cleansed in coke, sawdust, or wood wool scrubbers. It is already known that a successful bituminous coal suction producer, something on these lines, will soon be made public.

In the drawings which Messrs. Holzapfel & Cherry have been good enough to put at my disposal, see Plates II. and III., you will observe that the cleaning of the gas is wholly done after it has left the producer, by means of wet coke-scrubbers, wood wool scrubbers, and the like, but as suggested, the tar might be utilised by burning it in the producer itself, increasing the efficiency and simplicity of the plant. The plentiful supply of water is a very great advantage in the cooling and cleaning of the gas, for sea-water will have no deleterious effect upon it, also the small quantity of steam vapour required for its manufacture may be obtained from the same unfailing source, and there will be no necessity to store fresh water or filtering apparatus as is usual with steam boilers.

Again, as regards size of fuel, a colliery owner informs me that bituminous coal can be supplied direct from the mines of suitable size, as is done with anthracite peas, at a slightly increased cost; or the vessel itself could carry its own crusher to deal with the coal before delivery into the producer hopper.

REVERSING.

The 3rd difficulty, namely:—Perfect control of a gas propelled vessel—is our next consideration.

One of the main difficulties that confronts the gas engineer in applying gas engines for marine purposes is that of reversing. With small powers it is possible to reverse by means of a reversible propeller, the engine having only one direction of rotation. There is naturally a very serious objection to putting the reversing gear in so inaccessible a position as in the propeller, but at the same time, there is undoubtedly a future for this type for river and coast work, if made simpler and more reliable. One of the great advantages of this type in connection with suction gas plants, is that the engine continues to run while the vessel is being reversed, slowed down, or stopped altogether; and the advantage is this, that the heat in

the producer is sufficiently maintained by the continued working of the engine, for the production of good working gas. The main disadvantage with these reversible bladed propellers is a mechanical one, for after a spell of work the bearings in the propeller boss, in which the movable blades are mounted, get worn, the blades lose their alignment and are liable to jam when the gear attempts to move them, and however great the care in design, sea-water sooner or later gets within the boss and injures the gear.

On Plate IV. is shown a new type of reversible propeller in which the gear is designed to work in the water. It is of so simple a construction, (with all bearings of anti-corrosive anti-friction metal,) that it could with safety be applied to higher powers that those usually allowed in present day practice with reversible propellers. The blades are mounted on fixed pivots with a bearing supporting the blade where the greatest load is applied, and therefore, even if the blade is slack on its bearing there is no fear of jamming or getting materially out of line. This arrangement also makes the removal of a blade and its replacement a very simple matter indeed, and it can be accomplished without docking the vessel, if light. The rough model on the table may demonstrate these points more clearly. For higher powers up to say 500 HP units there is another system in vogue for reversing the propeller, viz :—A reversing gear, which may be a combination of bevel or spur gear and friction clutches, is fitted somewhere on the propeller shaft within the vessel and in an accessible position. With this type it is customary when driving ahead for the bevel or spur wheels to be out of gear. These only come into operation when going astern. There are many patented examples, by well known makers, of this method of reversing, which has the same advantage as the reversible propeller in that the engine only runs in one direction and may continue to run

whether the vessel is moving or not. But for powers above 500 HP the gas engines themselves must be made to reverse, for this dispenses with expensive and complicated clutches. Mr. J. T. Milton, the Vice-President of the Institution of Naval Architects has said in connection with this matter "that marine engineers who are used to big engines think the inclusion of clutches a very serious proposal, they are not used to clutches. If the clutch gets out of order then the screw is done for. For sea-going ships we want a rigid connection between engine and screw, the engine must have direct drive and be reversible." There are many methods of doing this, Mr. Cherry in the designs of marine gas engines, Plate V., Fig. I. and Fig. II. shows one system, in which he has double sets of cams and rollers, controlled by a reversing link, while Messrs. Crossley and Messrs. Thornycroft rotate the cam shafts. Another, by the author, is shown on Plate VI. Messrs. Crossley's marine engine is shown on Plate VI., Fig. I. There is no practical difficulty in reversing the gas engine provided a sufficient reservoir of compressed air is at command. This problem of reversing will be further dealt with in connection with the vessel "Lord Antrim."

ROTATION SPEEDS.

Regarding rotation speeds, the marine gas engine must follow the lead of the steam turbine to a certain extent. There is no steam turbine vessel afloat with less than two separate steam turbine engines and two propellers fitted, generally there are three or four, and often a fifth turbine to propel the vessel astern, so that in like manner, my proposal is that not less than two marine gas engines and gas plants should be fitted to each vessel, but actuated by a different motive from that which compelled the steam turbine designers to split up their power in this manner. In their case it was in order to get reduced propeller speed with economical velocity

and expansion of steam in the turbines. With the marine gas engine, it is suggested in order to avoid the difficulties that may arise from stoppage of a single gas engine. Apart from the main advantages which I wish to advance, there are far less risks when a vessel has independent units to propel it; we have recently had an example in the case of H.M.S. "Terrible," which broke one shaft near Hongkong, and came home the 10,000 miles with the other at a speed of 10 knots.

It may be here noted that the revolutions of the turbine engines of the "Turbinia" were anything up to 2,200 revs. per minute; this gives the very high velocity of propeller blades at their periphery of 267ft. per second, the propeller being 28in. in diameter; now internal combustion or gas engines are essentially high-speed engines, and can certainly follow this lead in driving high-speed propellers, and may also demonstrate how out of date are the arguments in favour of slow running propellers, and consequently unnecessarily heavy engines. The average rotative speed for cargo boats to-day is from 75 to 80 revs. per minute. This can be increased from 200 to 300% with an efficiency greater than that of a slower running propeller of larger diameter, and at the same time reduce the torsional stress upon the shaft by increasing its velocity of rotation. See Figs. 4 and 5.

We are indebted to the investigations of Messrs. J. I. Thornycroft, S. W. Barnaby, J. A. Normand, and the Hon. C. A. Parsons, for our increased knowledge of high-speed propellers and the great advantage of having two or more of these for vessels of all descriptions.

The important questions of cavitation, pitch ratios, disc areas, and slip are fully discussed by these experts in the Transactions of the Civil Engineers, 1905-6, etc., and are equally applicable to gas as well as steam driven propellers. See also R. Neilson's "Steam Turbines," for particulars of propeller tests.

THE BEST TYPE OF GAS ENGINE.

There is no question in my mind as to what type of gas engine we should adopt for marine purposes, the simplest is the best, and there is no type so simple and satisfactory as the four-cycle or "Otto" type, with its sequence of suction, compression, power, and exhaust strokes, taking place in each cylinder. This type of engine, with inverted vertical cylinders, has a mechanical efficiency of over 90% and a thermal efficiency

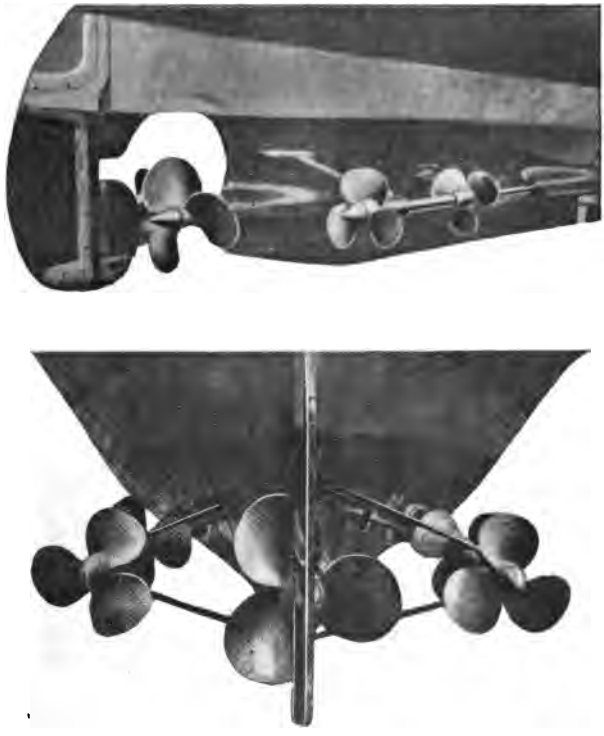


Fig. 4.

of 33%, and for a vessel requiring say 3,000HP, units of six single-acting cylinders, with pistons of say 21in. diameter by 24in. stroke, without piston rods, stuffing boxes, or piston water-

service, would be suitable. But where larger powers are required, then tandem cylinder engines with open cylinder liners should be adopted, having piston rod and stuffing-box between the tandem cylinders, where they can be easily inspected and adjusted.

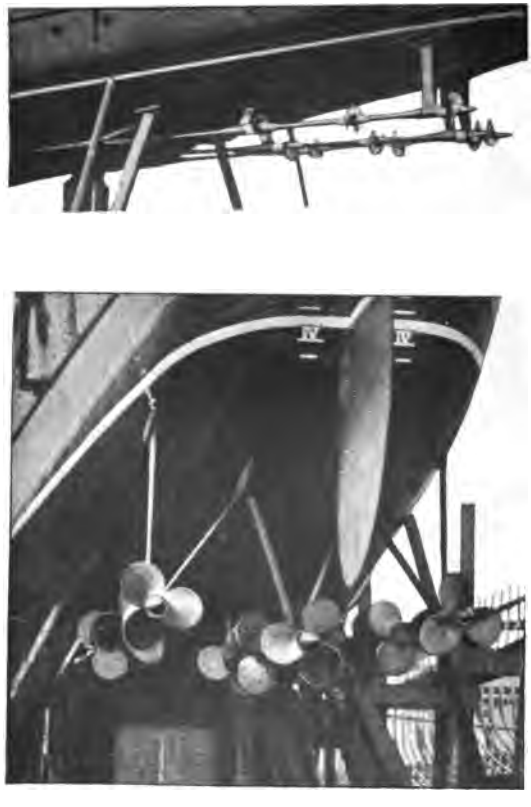


Fig. 5.

At present the author has not much confidence for marine purposes in the double-acting cylinder type, in which the piston is wholly enclosed and the internal conditions of the cylinder cannot be gauged with any degree of accuracy. Considering

the high temperature at which these internal combustion engines work, and which to a great extent accounts for their high thermal efficiency, it will not be wise to run any risk of firing a piston and ruining a cylinder liner because of the impossibility of easy inspection. Far better keep to the open cylinder type in which every working part can be seen and felt.

RANGE OF MEAN EFFECTIVE PRESSURES.

But the greatest of all difficulties in the application of gas engines for marine purposes, is the attainment of a sufficient range of mean effective pressures in the engine cylinders, so that like a steam engine, varying speeds, from full speed to dead slow, can be run without fear of stopping. We may reasonably assume that a maximum reduction of 60 % of the mean pressure leads only to a reduction of 35 % of the speed of rotation, or, if half the cylinders are cut out the speed of revolution will be reduced by about 32 %. Then by reducing the mean pressures in the remaining cylinders, the result will be a reduction of the effective turning effort to 25 % of that of full power, the speed of revolution will be something less than half that of full power. This reduction of speed is not satisfactory for marine purposes and it is doubtful whether gas engines could be run with so great a reduction of explosive charge. As an example, the proposed marine gas engine in the "Lord Antrim" with normal speed of 150 revolutions, cannot safely be reduced below 75 revolutions per minute, because with a light fly-wheel and possible miss-fires, the engine has not sufficient momentum to carry it over the compression strokes.

A solution has been proposed in a gas engine built on "Diesel" lines, with separate double-acting air and gas compressor pumps in two stages to force gas and air at high pressure and in varying quantities into the engine cylinders, which are to have only working clearance. This engine, it is

assumed, having one explosion per revolution per cylinder, can run at very greatly reduced revolutions per minute.

It is to be feared that this proposal brings in other difficulties worse than the complaint. Such a type of engine has never yet been built and made a commercial success. Some ten years ago it was my privilege to design a similiar engine to this, under the direction of Mr. James Atkinson and the late Mr. Frank Crossley, with separate gas and air single-acting compressors, driven by an independent crank from the engine crankshaft and arranged to deliver gas and air at high pressure into the engine cylinder. With that experiment, the main difficulty was to obtain a thorough mixing of the gas and air, of approximately equal volume, in the very short space of time allowed at the beginning of the power stroke, so that the gas consumption was very extravagant, and, added to this, the extra mechanical loss due to driving separate compressors made the engine much less efficient, and more costly and cumbrous, than the "Otto" type gas engine. This is not the solution for attaining various rotative speeds in the marine gas engine! And again, while the engines are running slow, what is to be done with the surplus gas that must be taken from the producers in order to keep up their temperature, and maintain them in a working condition? No gas engineer would dream of putting a gas-holder on board a ship, and the only alternative, therefore, is to waste the gas by opening the blow-off pipe to atmosphere and maintaining its flow by means of an exhauster.

The following solution at once meets all these difficulties, whether the vessel has to run full speed or dead slow, by a practical manipulation of the speeds of independent engine units. In running some of them ahead and some of them astern any speed in either direction can be readily attained by the officer in charge of the vessel on the bridge, and without stopping, except during

reversal, or when running slow for considerable periods, a single engine or the normal flow of gas through the gas producers.

By this means the author attempts a solution (analogous to the turbine problem) but on different lines from those apparently adopted by builders of marine gas engines of 500 HP and over. They rely on a large reservoir of compressed air for manœuvring and working the vessel up dock, in narrow waters, or when running dead slow in foggy weather, because with one engine unit, as has already been stated, the vessel cannot be driven by gas much below half speed. But to depend on compressed air at these times, when engines and producers should prove not their inefficiency but efficiency, is to stultify the whole subject of marine gas propulsion.

The one unit and compressed air system is just as unworkable as was the single steam turbine engine in the "Turbinia." It is no uncommon thing to be running dead slow for days, for instance, when a storm has wrecked all the lightships on a dangerous coast as at the mouth of the Hoogly, or when passing through the Suez Canal. Compressed air is certainly needed, but in the author's opinion, it should be only used for short periods when reversing the engines, and with two or more independent engine units, not only are the engines practically independent of compressed air for driving the vessel at any speed, but also the producers are maintained at an efficient working temperature.

SOME EXAMPLES.

Having advanced thus far with our subject, it may be asked, has anything yet actually been done in the propelling of vessels by gas power? And in reply I would refer you to papers given by Mr. J. E. Thornycroft, before the Institute of Naval Architects in 1904 and 1906. In these he gives several instances of river and coast vessels being driven by gas plants and gas engines. The first boat fitted, the "Emil Capitaine," 60ft. long by 10ft.

by 4ft, ran an average speed of 10 miles per hour for ten hours on a consumption of 412lbs. of anthracite coal, see Plate IV., Figs. 2 and 3. This consumption includes the fuel consumed by the producer, when standing by, during the previous twelve hours. This was the first vessel fitted with a gas engine and producer to run into the open sea; many other tugs and boats and larger vessels are similarly driven on the inland waterways, and coasts, of the Continent at the present time.

THE "EMIL CAPITAINE."

Plate IV., Fig. 2, shows plan and sectional elevation of the "Emil Capitaine." The displacement on a draught of 2ft. 6in. is about 16 tons. The propeller which is 3ft. in diameter works in a tunnel in accordance with the usual practice in shallow draught boats. A four-cylinder producer gas engine developing 60BHP at about 300 revolutions per minute is fitted. The cylinders are single-acting having a bore of 8½in. by 11in. stroke working on the "Otto" cycle. As the engine is irreversible, the reversing of

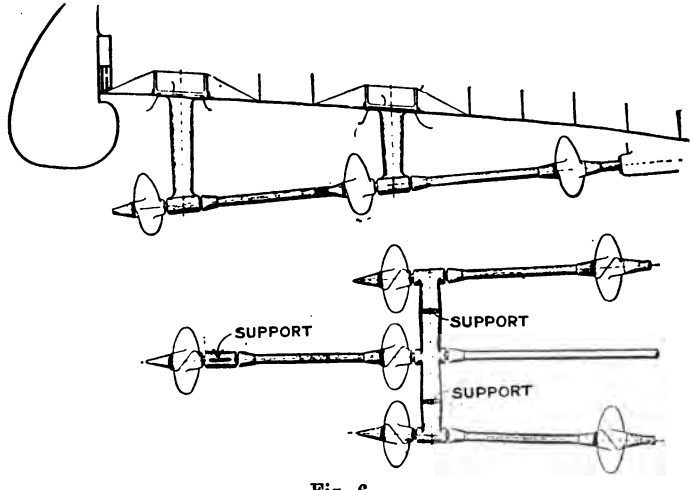


Fig. 6.

*Figs. 4, 5 and 6 by kind permission of Messrs. Longmans, Green & Co.

the boat is obtained by the fitting of a Thornycroft reversing gear. The producer is in a separate compartment divided from the engine by a light bulkhead. The producer-room can be entered from the engine-room on either side of the boat, but this is not often necessary if the engine has been started, as the producer contains sufficient fuel for a 12 hours' run. This is good news for stokers!

Plate IV. Fig. 3 shows the "Emil Capitaine" running at Southampton Water during the 1905 reliability trials at which she obtained a gold medal.

A canal barge called the "Duchess" was the first boat to be fitted with suction gas power in this country. She was equipped by Messrs. Thornycroft with a 25 HP engine and producer, but was originally propelled by steam. The installation of the producer gas plant effected a saving of 3ft. in the length of the engine room and about 4 tons in the weight of the machinery. Messrs. Thornycroft sent her on a tour of some six hundred miles through the English canals. During the journey the utility and efficiency of the system were amply demonstrated. The "Duchess" is 71ft. 6ins. long by 7ft. 1in. beam and carries 20 tons of cargo on 3ft. 6ins. draft.

For the purpose of comparison, tests were made on November 8th, 1904, with the "Gas Tug No. 1" and the "Elfrieda," a steam tug of very nearly the same dimensions and power. The "Gas Tug No. 1" is 44ft. 3ins. long by 10ft. 6ins. beam, and is fitted with one four cylinder 70HP Capitaine engine and suction gas plant. The "Elfrieda" is 47ft. long by 12ft. beam, and is fitted with a triple expansion steam engine, developing 75HP. At the towing metre the "Gas Tug No. 1." attained a maximum pull of 2,140lbs. and the "Elfrieda" a maximum of 2,020lbs. A run from Hamburg to Kiel and back was made by these two boats during very stormy weather at a maintained speed of 8½ knots; the consumption of fuel was measured for a period

of 10 hours and was as follows:—For the "Gas Tug No. 1" 580lbs. German anthracite, and for the "Elfrieda" 1,820lbs. steam coal. This shows an economy of 1 to 3·44 in favour of the gas plant. There are also vessels of 200 tons running on the Rhine, between Rotterdam and Cologne giving satisfactory results.

RELATIVE COST.

Messrs. Crossley Bros. have fitted a two cylinder engine into a canal barge, the results of which have not yet been published. Plate VI. Fig. 3 shows the Crossley gas engine.

The prices of small marine suction gas plants and engines are about the same as for steam engines and boilers of the same power. The following figures are interesting:

Engine.	BHP.	Cost of Engine and Producer.	Cost of Stern Gear, Propeller, Reversing Clutch.	Total.	If with Reversing Propeller.
Vertical Two-Cylinder	25-30	£450	£126	£576	Total £530
Vertical Four-Cylinder	50-70	£650.	£165	£815	Total £760

which gives 1 BHP for a little over £10, for larger powers there will be a reduction on this.

Messrs. William Beardmore & Co. are at the present time experimenting with a marine gas engine and plant of over 500 HP, and have fitted it into a vessel from which they have removed the steam machinery; and Messrs. Holzapfel & Cherry, of Newcastle-on-Tyne, are also engaged on a similar enterprise, the results of which are not sufficiently advanced to be included in this paper..

There are vessels running on the Caspian Sea driven by internal combustion engines supplied with oil in engines of the Diesel type. The "Vandal," built by Messrs. Nobel Bros., of St. Petersburg, has been running since 1903, and has 1,100 tons displacement, three propeller shafts direct coupled to motors of 75 kilowatt capacity, speed 7½ knots. The propellers are

reversed electrically. In this equipment, which has proved satisfactory, the engines drive dynamos electrically connected to motors on the propeller shafts, with a power transmission loss of 15% to 20%. Another vessel, the "Sarmat," built by the same firm, of 1,100 tons displacement, has two four-cylinder engines of 180 BHP each, at 200 revolutions. This also drives two dynamos and motors on to two propellers, and trades on the river Volga and Caspian Sea, speed over 8 knots.

YARROW-NAPIER TORPEDO BOATS.

Our Admiralty have a number of vessels with engines of the internal combustion type using petrol as fuel, and working on the "Otto" cycle, as well as torpedo boats and submarines (worked with petrol and oil engines) from 75 to 150 feet long. Messrs. Yarrow & Co. have built several. A torpedo boat by this firm, length 60ft., beam 9ft., attained a speed of 24/25 knots per hour. Comparing similar torpedo boats having internal combustion engines versus steam machinery, the following figures show the superiority of the internal combustion engine.

The Yarrow-Napier internal combustion engine torpedo boat referred to has five sets of four-cylinder engines, *i.e.* 20 cylinders in all, 6½in. dia. by 6in. stroke, running at 1,100 revolutions per minute, the centre engine only is reversed by a clutch. The three propellers have three blades of manganese bronze and about 20% slip, and as there are two engines coupled to each wing propeller, and one engine to the centre shaft only, the wing propellers are larger than the central propeller.

Yarrow Napier Torpedo Boat with Internal Combustion Engines.	**Yarrow Torpedo Boat with Steam Machinery.**
Length = 60 feet.	Length = 60 feet.
Beam = 9 feet.	Beam = 9 ft.
Speed, light, 25½ knots.	Speed, light, 19½ knots.
Speed with 3 tons, 24 knots.	Speed with 3 tons, 18 knots.
Radius of action at full speed, 250 miles.	Radius of action at full speed, 108 miles.
Fuel capacity, 1 ton.	Fuel capacity, 2 tons.
Lifting weight for transport by rail, 8 tons.	Lifting weight for transport by rail, 12 tons.

The speeds are given on the basis of both boats carrying a load of 3 tons. As in the motor torpedo boats there is only one ton of fuel, as compared with two tons in the steam driven boat, the motor torpedo boat would be capable of carrying one ton more armament than the steam driven boat. The load of 3 tons amply covers the weight of armament of torpedoes and fuel; and the above figures prove that with the same weight of fuel, petrol against coal, the internal combustion engine gives the vessel a radius of action nearly five times greater than the steam engine. It should be noted that a craft of this size and weight, namely 8 tons, can be transported with facility by rail from one coast to another, so that a port undefended one day might be placed in a state of defence the next.

Mr. W. W. May, of Messrs. Wm. Beardmore & Co., says, "that the subject of gas propulsion for ships is most absorbing, and since taking it up, we are more and more convinced that there is an immense future for it." The results of their experiments in the direction of marine gas propulsion, have been very encouraging, and had it been possible he would certainly have added considerably to my paper. Messrs. Beardmore's engine of 500 BHP has five single-acting cylinders with dry pistons. The reversing gear is not unlike an ordinary marine engine reversing gear. There are two cam shafts to reverse. The inlet cam shaft is rotated 90° and the exhaust shaft 110°, the action being carried out simultaneously. He has already published the weight of this engine and its producer plant as 65 tons total; and comparing two 1,000 HP Beardmore "Capitaine" gas engines of eight single cylinders each, with one 2,000 IHP. triple expansion marine steam engines and boilers, the weight of the two gas plants totals 240 tons and the weight of the similar powered steam plant totals 320 tons, or 33% heavier. Messrs. Beardmore are at the present time experimenting with various grades of

bituminous coal. It is interesting to know that the temperature in the producer room of all these vessels is comparatively low when compared with the stoke-hold temperature of a steam driven vessel.

Mr. Cherry has forwarded the following comparison with reference to his marine gas plant, Plate II.

1,400 I.H.P. GAS PLANT.

See Plate II.

1lb. per I.H.P. per hour	=	15 tons per day.
300 Days Steaming	=	4,500 tons.
Saving over Steam	=	2,250 tons.
Cost of Fuel at 6/-		£1,350.
Saving over Steam		£2,025.
Saving of over 5 % on boat costing		£40,000.
Total Weight of Machinery		267 tons.

1,400 STEAM PLANT.

1·5lb. per I.H.P. per hour	=	22·5 tons per day.
300 Days Steaming	=	6,750 tons.
Cost of Fuel at 10/-		£3,375.
Total Weight of Machinery		373 tons.

Sir William White states that modern twin screw engines and boilers have a weight of 1 ton for 6 to 7 HP. Messrs. Beardmore's figures for gas engine and plant give 1 ton for 8·33 HP.

It is not intended in this paper to deal at length with oil or petrol engines, as the author does not consider oil a satisfactory fuel for driving ocean going vessels. There are many objections to be raised to its use, except for special purposes. Whatever care may be exercised in isolating the oil-tanks from heat and any other source of danger, I feel confident that because of its great inflammability, as compared with coal, its use must be restricted to special services outside our mercantile marine. Also the price of oil being so liable to fluctuation, (due to oil trusts in highly protected countries as America and Russia) bars it from world-wide use in driving ships at sea. Coal is the fuel on

which we base all our calculations. It can be found in all quarters of the globe, and particularly in our own country, and the producer gas plant can be as readily adapted for burning different types of coal as the marine steam boiler.

Plates VII. and VIII. shew alternative drawings of the "Lord Antrim" of 375ft. long by 47ft. beam and 28ft. depth; gross tonnage 4,268, a steamer built and engined by Messrs. Workman Clarke, & Co. Ltd., Belfast and the property of The Irish Shipowners Co., Ltd., Belfast. I am indebted for information concerning this vessel to Mr. A. Basil Wilson, M.I.C.E., of Belfast.

STEAM INSTALLATION ON S.S. "LORD ANTRIM."

See Plate VII.

Number of Engines -	One Triple Compound.
Number of Boilers -	Two 15ft. 6in. dia. × 11ft. 6in., 180lbs.
Size of Cylinders - -	26in. × 43in. × 72in. dia.
Stroke - - - - -	48in.
Speed - - - - -	12·4 knots.
Total radius of action -	9,510 knots.
Donkey Boiler - -	One 11ft. 6in. × 9ft. 6in. at 90lbs.
Number of Propellers -	One 17ft. 6in. dia. 19ft. 3in. pitch.
Revolutions per minute -	67.
Displacement - - -	5,000 tons.
Displacement at sea, loaded	9,758 tons.

GAS INSTALLATION ON G.S. "LORD ANTRIM."

See Plate VIII.

Number of Engines, -	Three, Single Acting, six Cylinder.
Number of Plants - -	Four, Suction.
Size of Cylinders - -	21in. dia.
Stroke - - - - -	24in., 350lbs. Explosion Pressure.
Estimated speed - -	14·26 knots.
Total radius of action	16,826 knots.
Auxiliary Producer - -	30 I.H.P.
Number of Propellers -	Five, 11ft., and 8ft. dia. with 15% Higher Efficiency.
Revolutions per Minute -	150.
Displacement - - -	5,000 tons.
Displacement at sea, loaded	9,758 tons.

In Plate VII. the ship is shown with its steam-driven machinery as now in operation. Triple compound engines of 26, 43, and 72ins., diameter, 48ins, stroke, running at 67 revolutions per minute, and developing 2,360 IHP. Propeller 17ft. 6ins. diameter, 19ft. 3ins. pitch, steam pressure 180lbs. Consumption of coal per IHP per hour at the low figure of 1·33lbs. on trial trip.

On Plate VIII. this vessel is shown fitted by the author with gas producers and gas engines, the engines developing the same HP as the steam engines but running at the increased speed of 150 revolutions per minute.

There are four producers of the suction type designed to work with bituminous fuel, (see Plate I.) with dust collectors, superheaters, and heat interchangers, coolers and sawdust scrubbers for the cleansing of the gas before passing to the engines. The engines and gas plants of this installation take up rather less space than the steam plant and therefore allow more room for the coal storage bunkers. Each producer is supplied with a storage hopper of about 5,000lbs. coal capacity, which will only require feeding once every eight hours by means of the coal elevator and spiral conveyor shown on Plate I. The necessary starting-fans, centrifugal pumps for water circulation, and the coal and ash elevators, are driven by electricity from generators in duplicate, direct driven by small gas engine units of approximately 12 to 15HP, which also will be arranged to supply electricity to drive duplicate air-compressing engines for charging the air receivers shown on the deck immediately above the main gas engines. These reservoirs have from 20 to 25 piston stroke volumes of main engines in capacity, which will give ample margin for all emergencies. In the same space as these air receivers is a small starting suction plant of about 30HP which is arranged to supply gas to the two small starting units already referred to.

When starting up this plant, the fires are lighted in the producers the night before, to get them thoroughly warmed up. The starting air-fan must run from 15 to 20 minutes before each producer can give good gas for starting the engines. During this interval the blow-off pipe, 15 inches in diameter is open, and the poor initial gases driven off the fuel, are allowed to go to waste up the funnel. This is a convenient but not essential means for the conveyance of waste gas to the atmosphere. The fourth producer is for stand by purposes or for working deck machinery when loading or unloading cargo, for handiness and freedom from stoppage by frost, electricity or compressed air could be used for all deck gear. Steam power for deck gear is certainly not a success at the usual consumption of 7 to 10lbs. of coal per IHP; half of the heat being wasted to keep the pipes hot. These gas producers can remain for long periods, in some cases for months, with very low standby losses ready to give gas to the engines in from 15 to 20 minutes, and when once started into full operation by the suction of the gas engine pistons, need very little attention. The exhaust pipes from the engines are shown cooled by water-jacket, or by internal water spray, the latter arrangement requires

$$\text{Cubic inches water per explosion} = \frac{\text{IHP}}{\text{Revs.} \times \cdot 36}$$

in the length next to the engine, (see Plate VI., Fig. 2). The exhaust pipes are connected to the funnel. By this means the exhaust escapes to the atmosphere in the form of steam vapour at about atmospheric pressure. A diaphragm across the centre of the funnel prevents any danger of firing the gases blown to waste, when the engines are being slowed down or stopped. The air inlet pipe to the producers is carried down within the exhaust side of the funnel, so that some of the heat is transferred to the air, which by this means, and by passing through the heat interchangers, enters the producers at a very high temperature.

The air to the gas engines must be kept as cool as possible, and is kept as far away from any heating agencies, such as exhaust pipes. The air pipes pass through the deck forward of the funnel. In hot weather or tropical climates in order to maintain the engines at their full power, the air compressors may be run for cooling the air and gas immediately before admission into the engine cylinders, and by increasing the weight of the charge admitted, will increase the power of the engines. This can be done at little extra cost when the air compressors are not required for other purposes.

It will be noticed that the central shaft is fitted with a larger propeller than the two wing shafts.

These have two propellers carried on A frames from the bilge of the vessel, as shewn in examples of steam turbine propellers, Figs. 4, 5 and 6, and do not project beyond the lines of the vessel, and are thus satisfactorily protected. It is possible, as already intimated, with this arrangement of machinery, to run the vessel at any speed from full speed to dead-slow either ahead or astern. For example: taking the propeller going astern as having only 50% efficiency when compared with going ahead, by running the centre engine full speed ahead, and the wing propellers about full speed astern, the vessel can be practically stationary. Then by slowing down the wing propellers to half speed astern, the vessel can be made to move about quarter speed ahead, and as these engines can vary their speed from 150 revolutions down to 75 revolutions per minute, any speed in any direction can be attained by the vessel without stopping the engines. As a further example: when a gas driven vessel has to be slowed down, the first thing to do is to slow all the engines; if this is continued for any length of time, one or more of the gas producers may be shut down temporarily, and their production of gas practically suspended, the remainder working at about their usual load. If further reduction of speed is required, then

one engine unit at a time may be reversed, until the correct speed is obtained. As a rule these reduced speeds are only required at the end of a voyage, and then for two or three hours only, often less, and I contend that this system is sufficiently elastic to cover all possible circumstances. The suspended producers may, in from five to ten minutes, be put into work again. In narrow waters, entering or leaving port, or working up dock, the vessel is under as complete control as if fitted with the latest steam engines, and with no fear of the quality of gas being reduced. With such an installation, which occupies somewhat less space, less weight, and about the same cost as a steam installation, but with about 50% less coal consumption, who would fear a deep sea voyage if the machinery were in charge of experienced and capable marine gas engineers?

Turning our attention to marine gas engine design, it will noted that in the "Lord Antrim" each engine unit has six cylinders with cranks at 120°, three cylinders on each side of a fly-wheel mounted in the centre of the crankshaft, with enough energy in its rim to absorb, say three impulses from each cylinder, and the total energy in the fly-wheel rim to be about 18 impulses for the six cylinders. This weight will give ease in starting and will not prevent easy reversal of the engine.

STARTING AND REVERSING.

On Plate VI., Fig. 2. is shown a patented form of gas engine, with reversing valve gear, having the ordinary reversing link gear. With this arrangement all the valves of one cylinder are operated by one eccentric in one direction, and by another in the reverse direction, in the usual well known manner, and this is the only gear I know of its kind. Each cylinder is fitted with a compressed air inlet valve, which is also operated from the side shaft. These valves are of a very simple design, and automatic in action, so that in whatever position the engine stops, by simply turning on the compressed air,

having the gear in the right direction, the engine will immediately move off, and the admission of this compressed air does not in any way interfere with the admission of the combustible mixture into the cylinder. As a matter of fact, as the cylinders are fired, the compressed air is automatically shut out, and very little loss due to leakage of the compressed air is sustained, even if the engineer forgets to shut off. From the timing of valves given on diagram Fig. 7, and timing of the air inlet valves on diagram Fig. 8, you will note that the compressed air is admitted 15° before the end of the compression stroke, and is shut off 80° in the power stroke, before the opening of the exhaust valve. The half compression gear, which may be used for ease in starting, opens at 20° past out centre and closes at half stroke, so that it does not overlap with the admission of compressed air, which consequently cannot be wasted down the exhaust pipe.

TIMINGS OF VALVES.

COMPRESSED AIR STARTING AND REVERSING.

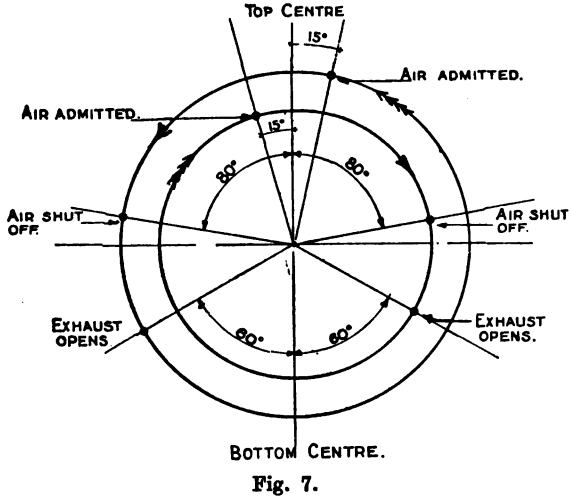


Fig. 7.

As arranged on each cylinder.

Supposing that the engine has suddenly stopped, and requires starting again in the reverse direction; the engineer puts over the reversing gear, and turns on the compressed air. The engine begins to move, and as soon as the gas stop valve is opened, the engine immediately gets up speed. In the six cylinder engine proposed, the crank-shaft, built up or solid, preferably in two duplicate parts of three cranks each, will have a very equable turning moment, and being carefully balanced, there will be little or no vibration transmitted to the vessel if the sequence of explosions in the cylinders are according to best practice, as settled in recent trials of internal combustion engines.

TIMINGS OF VALVES. PRODUCER GAS.

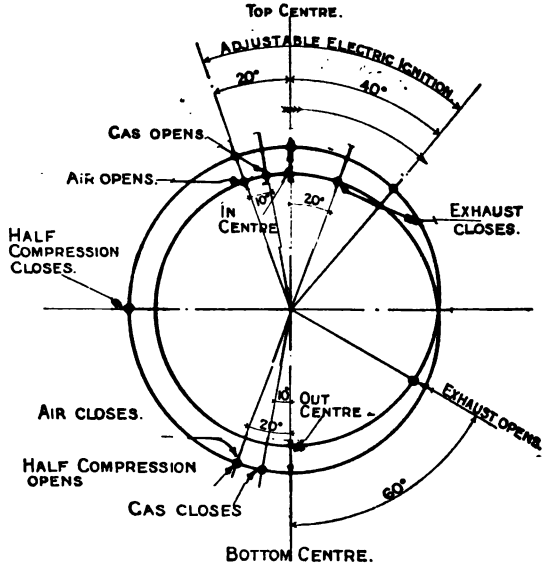


Fig. 8.

Direction of Rotation Ahead as shown.

Direction of Rotation Astern as shown, but reversed.

Three alternative systems of firing in a six-cylinder marine gas engine can be adopted. Their sequence from the following authorities is:—

153624, Standard Company;
123654, Messrs. Thornycroft & Co.;
142635, The Napier Company;

In all cases the cranks are at 120°.

Further, the engine must have open frames for the inspection and handling of the working parts, with a duplicate forced oil system to all bearings. For powers above 700HP units, the vertical tandem type is the most suitable and compact, as shown in Plate VI. Fig 1, a vertical marine engine designed by Messrs. Crossley Bros. It is of the very greatest advantage to keep the pistons of the open type, so that any undue heating of the pistons or piston rods may be at once noticed, and by arranging cylinders tandem in this fashion, the stuffing-box is placed in a position of great accessibility. Inverted stuffing-boxes underneath the cylinders and packed with metallic packing should be avoided. In gas engines, only metallic packing is possible, on no account must soft packing be used in contact with the rod. It is usual now to have a number of cast-iron rings at the bottom end of the stuffing-box, assisted at the outer end by anti-friction white metal rings in segments, between which oil under pressure is forced to lubricate the rod. This system of packing can stand any pressure up to 1,000lbs. per square inch, (producer gas never exceeds 450lbs.), and with water circulation through the rod there is no fear of over-heating. The pistons also are supplied with seven or more cast-iron rings, oil under pressure being supplied to the piston, liner, and crosshead.

Again, each cylinder must be provided with double electric ignition with sight-holes, so that the spark is seen by the engineer while the engine is running. The current may be either

high or low tension from batteries or magnetos, both are equally good. Also the electric ignition gear should be so designed that the moment of sparking is adjustable to a range of say 60°; 20° before the dead centre, and 40° after the dead centre on the power stroke. See Fig. 8. When starting or running slow, it is necessary to retard the moment of sparking until the crank is well over the dead centre, but when running full speed, the moment of spark may be adjusted to 20° before the in-centre is reached, as there is a small interval of time between the moment of sparking and the moment of inflammation of the charge in the cylinder; also the electric ignition gear must be so designed that while the cylinder is working off one sparking box, the other can be shut off, cleaned, adjusted, and re-fixed without

MARINE GAS ENGINE—SIX CYLINDER TYPE.

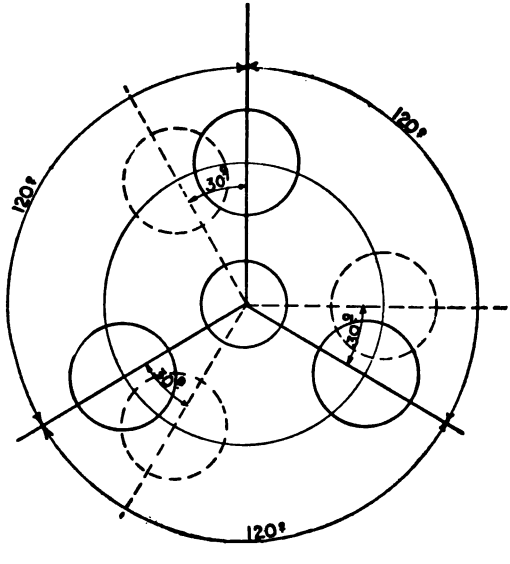


Fig. 9.

Positions of Cranks for easy Starting and Reversing by Compressed Air.
Cranks in full, forward of flywheel; Cranks dotted abaft flywheel.

stopping. The sequence of valve timings is shown on Fig. 8. The timings are approximately correct for producer gas, but as the quality of gas from various grades of fuel varies considerably, say from 80 B.T.U. to 180 B.T.U. per cubic foot, the opening and closing of the valves, especially of the gas and air valves, may require modification to get the most economical results. This diagram speaks for itself and requires no further explanation,

Referring to Fig. 7. of the timing of the valves for starting and reversing by means of compressed air, these are so arranged in conjunction with positions of cranks, as shown on Fig. 9., that in whatsover position the engine may stop it may

TIMINGS OF VALVES.

PRODUCER GAS. WITH ECCENTRIC VALVE GEAR.

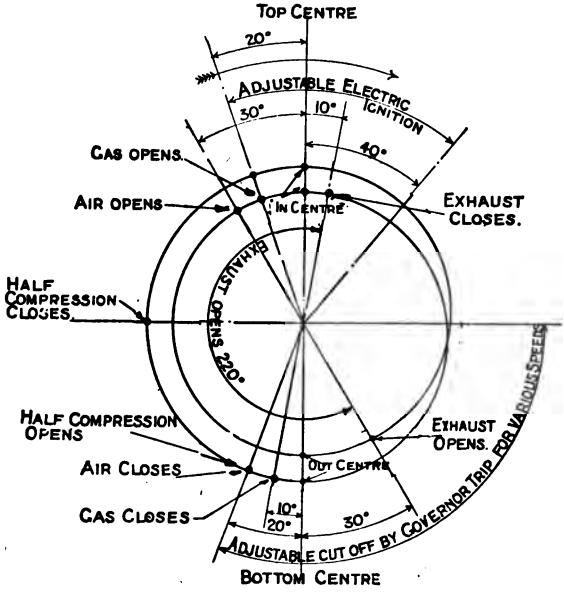


Fig. 10.

Direction of Rotation Ahead as shown.
Direction of Rotation Astern as shown, but reversed.

be readily started in either direction. It is customary when the engines are stopped, for the engineer to put over his gear to "astern," he will soon discover the best position for starting and will adjust the cranks accordingly. The six crank engine under consideration has three forward of flywheel, and three on the after-side; their relative positions are shown on Fig. 9, and for easy starting have an angular difference between each set of 80°, so that only one crank out of six can be on the top dead centre at the same time, and as the cranks are set at an angle of 120° with each other, one or two cranks must be enclosed between the positions of air shut-off, as shown on Fig. 7, which covers 160°. Also, the admission of compressed air being automatic and controlled by fixed cams, is practically fool-proof, the air pressure cannot be wasted through the exhaust or admission valves, or when the engine is on half compression.

TIMINGS OF VALVES.

POSITIONS OF ECCENTRIC ON SIDE SHAFT.

RUNNING HALF SPEED OF ENGINE SHAFT.

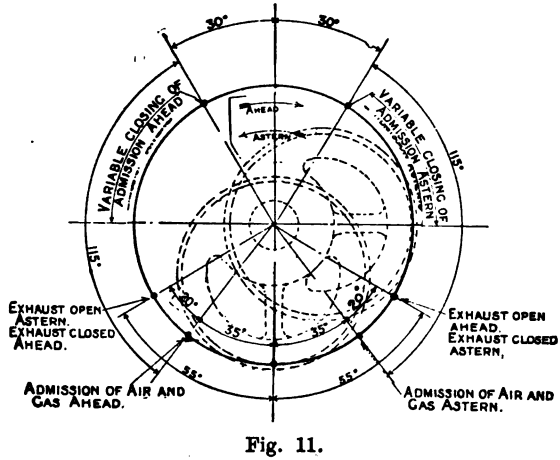


Fig. 11.

Special stress is laid upon the principles involved in the reversing of the gas engine because of its immense importance in connection with marine gas propulsion. Diagrams of the timings of valves in connection with the eccentric valve gear are shown on Fig. 11.

Objections may be raised to the use of a flywheel on board ship, probably due to the fact that heavy flywheels generally form part of a land gas engine, but in marine work where fluctuations of speed are of minor importance, and when multiple cylinder engines are used, the flywheel may be of very greatly reduced weight, as already stated, and experience has proved that gyroscopic action may be neglected, except when the wheel is placed athwartship.

With large marine gas engines it is estimated that their cost will be about the same as high-class steam engines of the same power, but a gas producer can be made much more cheaply than a steam boiler, as the plating may be of the very lightest description. For instance, the shell of a 500 HP producer need be only $\frac{5}{16}$ths. or $\frac{3}{8}$in. thick, with a lining of fire-brick within.

I have refrained from giving you any sections of suction plants, the technical press having been inundated with these recently; reference can be made to Mr. Thornycroft's paper, also to the paper on "Producer Gas Plants," by Mr. T. Rigby, delivered before this Association last year, and a recent publication by Mr. Dowson on "Producers." These will give you more information than I can as to the construction and internal arrangements of the gas producer apparatus.

IMPERIAL INTERESTS.

And lastly, this subject is brought forward in the interests of Imperial defence. You will have noticed drawings of a battle-ship in a recent engineering periodical indicating the difference in space occupied by proposed gas versus steam

machinery. It is patent that a well directed shot in the machinery space of such a ship supplied with steam would have a far more terrible effect than in a ship propelled by gas. In the one you have a number of boilers and superheaters, with their steam and feed pipes under high pressure, any part of which if perforated by an enemy's shell would either sink or do irreparable damage to the vessel. These vital parts have to be protected by an armour-belt, which as an average is $\frac{1}{3}$ of the total cost of the vessel, whereas, in a gas driven battle-ship, the engine cylinders only contain pressure, so that if a shot perforated any part of the machinery, although it would of necessity prevent that part from working, there is no reason why any resultant explosion, apart from the shot itself, could not be avoided if care be taken. There would certainly be danger if the gas producer were damaged, and air drawn in above the furnace so as to form a combustible mixture with the gas, but even then the explosion would not have the devastating effects of a steam boiler explosion. With gas, the armoured belt could be of much reduced dimensions, and thus allow heavier armament, and with an extended radius of action due to less consumption of coal per IHP; the vessel would be a much more formidable opponent.

IMPROVED BATTLESHIPS.

In H.M.S. "Dreadnought" driven by steam turbines, extra engines, termed cruising engines, are required, to drive the vessel at a reduced speed for cruising purposes without undue waste of fuel. Such additional machinery is not required with a gas engine installation, and is certainly a point in its favour.

Since the Russo-Japanese war it has been the aim of our naval authorities to build vessels in such a way as to approach the enemy unobserved. This effort has been the cause of the introduction of the submarine, and as no one is in favour of this

class of warfare, why should not our naval lords turn their attention more in the direction of making our battleships and cruisers as difficult of observation as possible. Are not their huge funnels with the heavy cloud of smoke that always accompanies them, the best possible signals to an enemy to prepare for action.? In this connection oil engines have been advanced as suitable for propelling war vessels, or what has already been done with excellent results, steam turbines driven by oil fed boilers, as in H.M.S. "Gadfly," using crude Texan oil. But we are dealing particularly with coal, and as there is no such thing as smokeless coal, in this connection a few observations from a captain, of over thirty years sea experience, may not be out of place. Captain Watson says :—

"I am glad to give you what I believe to be reliable information as to the distance smoke can be seen on the horizon. This may be, with the naked eye in clear weather, anything from 30 to 50 miles. The greater distance I mention would be with a high barometer, say 30·30, and if the vessels have the wind aft, to counteract the wind she would make with her speed through the water, the smoke would then arise almost vertically, and generally forms a cloud above the vessel. With a heavy atmosphere the smoke would hang dead and not be seen nearly so far. I have frequently met in different parts of the world many of our battleships at sea, and have always seen the smoke with the eye before being able to discern the tops of their smoke stacks, even with a good glass. These distances are based on the mean height of eye of 20ft. above the water. I do not think a good glass assists much as far as distance is concerned, but I have frequently had to use the naked eye to sweep the horizon after fishing around with the glass unsuccessfully. But when once objects, say masts or funnels, appear, the difference between glass or no glass will be about a mile or more, according to the bulk of the object. Navigation

not being one of the exact sciences, owing to the erratic and constant movement of the surface water, influenced by tides, currents, winds, moon, barometer, etc., we cannot in practical navigation guarantee perfect accuracy."

It is possible at higher altitudes to see the smoke-cloud at a distance of 70 to 80 miles and as much as 100 miles.

I therefore submit to you to-night the alternative of marine gas propulsion with the greater confidence because gas plants require no funnels nor do they emit smoke. Very few of us I contend desire war, but we do need to keep command of the sea, and we must possess a navy strong enough, with a maximum of efficiency and a minimum of waste, to keep open the roads by which our people are fed. For while we rightly pride ourselves on our island home, the fact remains that the moment our sea-roads are closed by an enemy, who may have advanced more rapidly in efficiency, we are in a state of siege. Some people talk as if the fact of our being an island in some way gives us supremacy at sea. Nothing is further from the truth, it is because we are an island that we are in such constant need of maintaining our supremacy at sea. "An island power must either command the sea or in the long run lose her independence. * All history shows that it is far easier to transport an invading force by sea than it is to do it by land." Therefore, let us keep our navy up-to-date, and I would urge the advantage of marine gas propulsion as a valuable step in the direction of efficiency.

My intention had been also to show you a battle-ship fitted up in the same manner as the "Lord Antrim" and I have spared no effort to obtain the necessary drawings, but in this have not been successful. There is no serious difficulty in fitting up battle-ships having from 20,000 to 50,000 IHP, seeing that we already know that the total plant will have less weight and occupy less space than a steam plant of the same power.

* *Vide* "THE SPECTATOR," 1906.

Gas engineers have already been able to obtain 1,500 IHP out of one cylinder. Then also the fire-grate of the gas producer has only 0·05 square feet per HP, compared with 0·2 square feet per HP of the ordinary steam marine boiler. The fire-brick lining of the gas producer is the heaviest part of the whole plant, and if the fire-bricks were formed hollow or with internal air-ports, their weight could be reduced quite 40 to 50%.

Having battle-ships without smoke, another step gained would be to dispense with the funnels, by utilizing the hollow steel masts which carry the fighting tops, for the purpose of blow off gas and exhaust pipes, the masts being carried a sufficient height above the platforms for these purposes.

In conclusion, the author has to acknowledge his indebtedness to many firms and friends who have generously assisted him in the preparation of this paper.

DISCUSSION.

The PRESIDENT (Mr. W. Henry Hunter), in declaring the discussion open, said that the subject of Mr. Coster's paper was of the deepest possible interest. There was hardly a matter of more vital importance to the whole of the community interested in the question of over-sea trading and in Imperial defence than the substitution of internal-combustion engines for steam propulsion. He was pleased to hear that at least one firm in Manchester, thirteen years after the city had become a port, had taken up the construction of engines for driving small barges on small canals; he was not previously aware that even that height had been attained in the city. It was astonishing to him that with such an object before their eyes, Manchester engineers were doing so little in connection with the matter of marine propulsion.

It was obvious that the great point in connection with gas engines was one of ready handling of the vessel propelled by engines of that type. He had had a large experience with the working of gas engines, but none with a reversible gas engine. He hoped those who took part in the discussion would make up for this lack on his part so that the different methods proposed by the author for reversing might be subjected to competent criticism; but reversible the engine must be. His own opinion as to the author's proposals for reversing, was that they were beyond the scope of consideration; it was a perfectly impossible proposition to suggest that the reversal should be effected by means of a movement in the blades of the screw below the water.

Further, a difficulty arose, which Mr. Coster had dealt with with perfect frankness, and which related to occasions when it was not necessary to reverse or stop the engines but merely to slow them down. An ingenious device, which was probably a practicable one, had been offered in the paper, but to him (Mr. Hunter), who had had an unhappy experience in the matter, this device had one absolutely fatal objection. On several occasions in his personal experience he had dealt with cases of serious damage to ship or standing structure, due entirely to the fact that when the engineer was ordered to go astern he went ahead. A very experienced sea-going engineer had informed him that this mistake happened every day, though perhaps it was only once in a thousand times that an accident occurred.

The method proposed would complicate the duty laid upon the man in the engine room; to slow down, instead of half speed ahead, or half speed astern, as was the case with an ordinary telegraph, and an adjustment of his starting wheel, he had to go ahead with one engine, another astern, and another engine ahead. This would be very dangerous with a boat coming, say, up the Ship Canal. He had had lock gates in the

Canal carried away on three occasions from that one single cause—viz., that the engineer had gone ahead when told to go astern.

These accidents were pure mistakes due to the fact that the "human machine" is an imperfect one; they were similar to the observations made by Captain Watson relating to sea navigation: "There were so many surrounding circumstances to affect it, that it ceases to be an exact science." A man does a thing a thousand times exactly as told by the telegraph, but in the stress of the difficulties of the engine room, the next time, his attention is distracted, the mind fails to respond—Was there anything to be wondered at if he went wrong?

That was a difficulty which had to be got over, but the method proposed would not meet the case. No doubt there was some method, and he was sure that internal-combustion engines, as one's own experience showed, would be more reliable and efficient in their working if those difficulties of reversal could be got over.

Personally, he was disposed to think that the gas producer plant would give way to the oil-driven engine, using heavy Texas oil. No doubt there was a difficulty in the latter, as the supply of Texas oil was at present an unknown quantity, although probably there were unlimited supplies beneath the earth's surface. In H.M.S. "Dreadnought," referred to by Mr. Coster, where the high-speed plant was provided by steam turbines, and the cruising plant by reciprocating engines, the whole of the many minor engines—about 20—with which the boat was fitted, were oil engines of the four-cylinder Diesel type, each engine representing about 160 IHP. With gas engines and producer plant were introduced difficulties in connection with tar, which was the bane and the trouble with such plants. Such difficulties did not occur with oil engines.

Engineer-Commander BALL, R.N., (visitor) in mentioning that he was present at the kind invitation of the ex-President, Mr. Robert Matthews, said that although he was officially attached to the Admiralty, any statements which he made should not in any way be interpreted as the opinions of the Admiralty, but should be understood to be simply an interchange of opinions between himself and fellow-engineers.

Naturally his experience had been in connection with warships, between which and a ship engaged in commerce there was a great deal of difference; in a battleship they were tied down completely, the machinery being placed in the smallest possible space. For instance, if there was a leaking joint, in order to get at, many joints would have to be broken and afterwards re-made. As warships at sea had to be kept ready for instant service, the leaky joint might have to remain so until a dockyard was reached; whereas in an ordinary ship there was generally plenty of space to at once get a spanner at work.

In reference to the diagrams giving comparisons of the heat balance sheets for different classes of power plant, he noted that with turbines or reciprocating engines, the heat lost worked out to about 90% of the actual heat got out of the coal. With gas engine plant, the percentages given were certainly better than steam, but still were very low.

Before reading the paper, he thought that it would have claimed that the gas engine could do a great deal more as compared with the steam engine than was shown in the paper. Certainly, as regards economy of the gas engine, there was a good claim, but not as much as he expected. The difficulty with steam engines was the loss by the latent heat. Taking, for instance, the case of the "Mauritania," the IHP of which was about 68,000, this vessel would probably burn about 1·5lb. of coal per IHP, which equals about 1,000 tons a day when steaming across the Atlantic. After making an allowance of 20% for loss

by radiation in the boilers, heat lost up funnels, the latent heat in the steam accounted for about 500 tons of coal, this being wasted in simply converting the water into steam. The water was converted into steam by that expenditure of fuel only to run through the engines and disappear in the condenser. It seemed to him that if someone could find some working fluid which would decompose the water before it was used, and thereby get out the latent heat, the steam engine would then be able to hold its own.

The President had called attention to the difficulties which arose in the reading of the telegraph, and had quoted several instances in which locks in the Manchester Ship Canal had been damaged due to the telegraph not being read correctly.

On war vessels definite orders were given to the chief engineer that he must be down below in the engine room when going into or out of harbour, or through a tortuous passage, these orders being solely to see that the telegraph is obeyed. His (Commander Ball's) experience was that the man who was working the engines sometimes formed a mental picture of the telegraph which was absolutely the opposite to what was intended.

With the system proposed by Mr. Coster, it would make it still more difficult for the engineer when he had to attend to three or four telegraphs ringing all sorts of orders.

In the Navy, the vessels of the Fleet usually cruised at sea in two lines, the lines being kept a certain distance apart and the ships in each line a certain distance apart from one another, and if this was not observed, the Admiral would ask for an explanation. With any vessel this often meant that the speed had to be regulated to a single revolution, and that a man had to be constantly by the throttle and the revolutions counted. Where would that man be if he wanted to regulate to one revolution faster or slower with a gas engine? Some other means than those proposed were required for getting regulation

of speed out of the ship. He did not think that by reversing one engine and going ahead with the remainder, that an engineer could, in the short time available, give the same effect to the speed of the ship as would be caused by increasing or decreasing the speed of a steam engine, fitted in a similar ship, by one revolution. The steering of the ship would not be improved.

Mr. Coster had mentioned that one man who "would bless the gas engine" would be the stoker. When it was considered that these men shovelled coal in which was only wasted in radiation and turning the water into steam, finally to disappear out of the condenser overboard, it would be admitted that these men would certainly bless Mr. Coster, and so would the owner of the vessel if he does not lose his ship by faulty means of going astern and so forth.

As regards steam turbines, he had not been "shipmates" with this class of plant, and had only had experience many years ago on a vessel with one of Parsons' small turbines for driving a lighting dynamo. This was a wonderful little engine, and ran at 10,000 revolutions a minute night and day for six months, with just a rest on different occasions for a general clean up.

As a naval engineer, he personally had no doubt the steam turbine had come to stay; and if only for having got rid of the crankshaft, thrust block, horrible slide valves, weighing, perhaps, 3 or 4 tons, and which had to be pushed up and down with a reversal of stress at top and bottom, he thought the turbine engineer had something to be thankful for.

Attention was drawn in the paper to the fact that producer gas was liable to explosion. In warships all sorts of holes and corners are made into coal bunkers, and the coal was bunkered where it was at all possible to do so. Occasionally one heard in the papers of a coal bunker explosion. If that happened at

present with bunkers which they tried to ventilate, what would happen with suction gas?

Mr. Coster had drawn attention to the many grades of suitable and unsuitable bituminous fuel. He (Commander Ball) gathered that anthracite should be used if this could be obtained. The Navy practically always used anthracite fuel; there were certain grades of bituminous fuel which were more or less unsuitable, but progress was being made, and he hoped one day all grades would be suitable. Of course, bituminous fuel was the coal usually burnt in a boiler, and was fairly cheap compared with Welsh anthracite.

The author had also mentioned that shipowners would have to insist upon a correct analysis being supplied prior to delivery so as to ensure gas producing qualities. He (Commander Ball) had been in various parts of the world buying coal, not for a shipowner but for the Government, and it seemed to him that you did not always meet a honest man who was dealing with coal. He would on one occasion have been short of some 20 or 30 tons out of 120 tons, if his staff had not kept their eyes very wide open.

As regards reversing, there was of course an alternative scheme for doing this, viz., by the introduction of clutches and gear wheels. He was glad to see Mr. Coster did not approve of that method, clutches and gear wheels were not wanted down in an engine room. The reversible propeller would be satisfactory for small boats, but he did not think it would be a success in the Navy with warships.

He was also glad from the point of view of bunker explosions that Mr. Coster did not propose to fit a gasometer on board ship.

A point which had not been dealt with in the paper, as regards warships, was, they had some hundreds of auxiliary engines on board. What kind of engines did Mr. Coster propose these should be? Probably he proposed the steering engine

instance, if 10 or 15 years ago anyone had said they could put a suction gas plant down which would make its own gas, he would have been laughed at, and so, many of the anticipations of Mr. Coster would probably be laughed at. The many claims put forward in the paper were worthy of the serious consideration of the Association, and he thought no apology was needed from Mr. Coster for introducing this paper.

One fallacy which was very common, and which Mr. Coster had apparently fallen into, was that with respect to "conserving the coal stores." If the cost of motive power, either steam or gas, was to be greatly reduced, the demand for power would be increased; and if it were possible to use the steam engine for almost any purpose at little cost, there would be such a run on the coal reserves that they would be exhausted all the sooner.

An important fact also not to be lost sight of, was that since the introduction of suction gas plants, the price of anthracite had risen by about 50%, and a very little further increase would bring the cost of power up to that of the steam engine.

Mr. DANIEL ADAMSON said there were some points which he would be glad if the author could make a little clearer.

On page 208 it stated that "as far as is at present known, steam turbines fall off more rapidly in thermal efficiency than reciprocating engines." Was this falling off when the load was reduced, or was it when the turbines became older?

Mr. Adamson further mentioned that from the reference on page 216 to the "Lord Antrim," it would appear that gas engines and producers had been fitted to that vessel, but from the references on pages 232-3, apparently the vessel had not yet been so fitted. Would Mr. Coster make it plain whether he had actually fitted this vessel with gas producer and engines?

Mr. W. G. GASS asked what would be the effect on the gas engine if the propeller were to race when the latter was out of the

water; would any accident then happen? He would like to know the method of governing proposed by the author.

Mr. GEORGE SAXON stated he would like to compliment Mr. Coster upon his very interesting and valuable paper. At the same time, it appeared to him that the only real effective reason for the installation of gas engines and gas plants in marine vessels was the point of economy; but there were many disadvantages attending the installation of a gas plant as compared with a steam turbine installation. The simplicity and the fact that the latter plants were already used for such purposes were points in their favour, but with the installation of gas plants there would be a great number of difficulties to be overcome. In that respect, he thought Mr. Coster's proposal would meet with a very great amount of objection.

There was no doubt that the steam turbine as brought to efficiency by the Hon. C. A. Parsons was certainly a plant that would require a deal of displacing. At the present time it was not at its highest efficiency, but in the future, although, as Mr. Coster had stated, the improvements which could still be made could only be of a very small character, even those improvements would make it still more difficult in the future to displace that motive power.

He realised that Mr. Coster in his advocacy of the marine gas power plant was an enthusiast, and had it at heart from his practical everyday dealing with this plant; and he had laid down the points in an exceedingly able manner. When consideration was given to the very great advances which gas plants had made in the last few years, it was no wonder that the claim was now made by Mr. Coster and put before engineers for adoption. It was well known that in land practice it had of late made very great strides, and had certainly proved an exceedingly dangerous

competitor to steam power, but it would take some time before it displaced steam.

Mr. E. P. Hetherington asked whether the author could inform him if it was correct that recently one of the largest gas power plants made in England, and shipped abroad, had proved an entire failure, and that steam power had been substituted for same.

Mr. J. Wright mentioned with regard to the space occupied by a gas plant, that Mr. Coster had stated that the fire-grate of the gas producer was only 0·05 sq. ft. per HP, compared with 0·2 sq. ft. per HP for steam boiler plant. As a matter of fact, 10 HP per square foot of grate was a very ordinary duty for a Lancashire boiler, and even 15 HP per square foot of grate was not uncommon. Why had Mr. Coster stated that 5 HP per square foot of grate was an ordinary allowance in a marine boiler? He (Mr. Wright) was under the impression that the consumption per square foot of grate with forced draught in a marine boiler rose to 40lbs., and sometimes more.

Mr. A. Vennell Coster, in replying to the criticisms of the various speakers, said that the President had mentioned the difficulty that was experienced with men in the engine room in not fulfilling their orders correctly, the engine being sometimes put to run ahead instead of astern. He (Mr. Coster) did not suppose that could be eliminated, whatever type of motive power was used. His experience was that sometimes they had to run the steam engine ahead in order to run it astern; for often the cranks were in such positions that the engine would not start in the direction required, and they had to be turned round slightly in order to get them in a better working position.

The President had also stated that he thought there would be a difficulty owing to the ship being driven by a number of units.

That difficulty, however, had already been tackled in the case of steam turbines, and there was nothing new or novel in his (Mr. Coster's) proposal. In the "Carmania" there were three shafts, each independent of the others; and in the "Dreadnought" he believed there were four shafts, each of which could be made to go in either direction, at least one or two of these were reversing shafts, and the whole plant was controlled from a starting platform above the engines, where the engineer in charge had the telegraph, telephone, pressure gauges and levers grouped for each engine unit, similar to a switchboard, and there he received his instructions from the bridge as to which engine to put astern and which to put ahead. Steam turbines could not reverse, and accordingly they had put in reversing turbines, these were on different shafts, and therefore his (Mr. Coster's) proposal to install a number of units in the gas engine driven ship was simply following on the lines adopted by turbine engineers.

He was disappointed that Engineer-Commander Ball had not been "shipmates" with the steam turbine, for if he had, a number of his points would not have been raised. He had spoken of the difficulties which would be experienced with the gas plant. As stated in the paper, with the gas producer plants themselves the difficulties are very much minimised, the stoking difficulties disappear, instead of the men having to throw the fuel on the boiler fires, there would be a large hopper from which the coal would be fed to the producer automatically.

Commander Ball had then spoken of the troubles which arise owing to weeping joints in cramped positions, and the inability to caulk them. With suction plant all those difficulties would be swept away, because if a joint slightly leaked air would be drawn into the pipe, and the gas would not come out of it. As a matter of fact gas plants worked at a little below atmospheric pressure, the suction of the engine drawing the gas from the

producer; therefore, if the pipe was leaking there would be no external difficulty.

Then as regards coal consumption and the difficulty due to the bunkers being in different positions. Evidently the 100% increased thermal efficiency of gas over steam was not sufficiently appreciated in this criticism. On the "Mauritania" he understood that the average daily consumption was 1,000 tons. With gas only 500 tons wonld be necessary, consequently more room would be available for the deck armaments and ammunition storage, he thought Commander Ball must agree as to this great advantage which would give greater elasticity in design of battleships.

In reply to Mr. Gass's query respecting damage to propellers, he did not suppose any propellor had yet been made which would stand the blow of a piece of wreckage. If a piece of wreckage struck a reversible propeller the blade would probably go much easier than if it was solid on the boss.

Mr. HUNTER asked would not all the blades go.

Mr. COSTER stated he did not think so if the blade swept the wreckage away. It was a common occurrence to have a single blade broken off at the root.

Respecting racing at sea. Running at high rotation speeds with less diameter propeller, the propeller would be much more immersed in the water than with a larger propeller, and was, therefore, less subject to racing.

In respect to the steam turbine he had nothing to say against it, it was a most magnificent piece of machinery, but was very delicate. He did not suppose any marine engineer could doctor it at sea if it went wrong, it would have to remain wrong until the ship arrived at port. He did not think there would be any more difficulties with the connecting rods of gas engines

than with steam engines, particularly with single-acting tandem type cylinders with no reverse strains.

Of course, as Mr. Ingham had said, the paper was largely anticipatory. It would be noted from the paper itself that he had endeavoured to tabulate all that was being done in connection with the gas driving of vessels. Messrs. Beardmore had spent a considerable amount of money in developing this idea of gas propulsion for marine vessels, and there were other firms also who were determined not to give it up because of preliminary unsatisfactory results. He thought it might well be left to these firms to develop and bring the subject to a definite and successful conclusion. Mr. Ingram's remarks *re* "conserving the coal stores" are certainly interesting, but inconclusive, and if correct would paralyse all efforts towards increased economy in any direction.

Regarding Mr. Adamson's two first queries, his reply to both was "yes," also that in the "Lord Antrim," he (Mr. Coster) had specially designed and fitted up that vessel with gas power plant for the purpose of obtaining a correct comparison of weights, space occupied and adaptability as regards "steam" versus "gas machinery.

He was obliged to Mr. Wright for correcting his figures relating to grate areas, he had unintentionally mis-stated the facts of the case in this respect. The figure should have been ·09.

The method of governing he would suggest for the marine gas engine would be by the throttle. When the engineer received a message from the bridge to go three-quarter or half speed, it would only be necessary to just close the throttle to each engine, or to the engine delineated on the telegraph, by simply shutting off a little gas, and the engine could be slowed down, and then, if necessary, reversed by the compressed air from storage tanks. He did not anticipate any greater difficulty than was at present

experienced with reciprocating steam engines in starting, stopping and reversing.

Mr. Saxon had mentioned the simplicity of steam turbines. He agreed with him, and believed gas engines also would be greatly simplified in the future. The advocates of gas-propelled vessels had time on their side. Greater difficulties had been faced in the past, and at one time no one thought that ships could be driven by turbines. It would be the same with the suction gas plant: it must advance, and thus bring about greater economy in the use of coal. He believed that the *bonâ fide* examples he had given of vessels driven by internal-combustion engines were sufficient to demonstrate that very real progress was being made towards the goal they had in view.

Mr. ROBERT MATTHEWS said he wished to propose a vote of thanks to Mr. Coster for his admirable paper. Of course, like all other papers which were anticipatory, there were many missing links. Mr. Coster had been very good to devote the time and attention in rigging up engines in order to obtain information for the paper.

Mr. HENRY WEBB seconded the vote of thanks.

The PRESIDENT (Mr. W. Henry Hunter), in closing the proceedings, said that Mr. Coster, in his reply to the discussion, had suggested that it should be left to Messrs. Beardmore and Messrs. Thorneycroft to work out the idea of marine gas propulsion. That, however, was not what was wanted. The observations made by the various speakers had been made with the intention of getting Mr. Coster to do that work. It ought to be done here in Manchester.

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8 Plates follow illustrating this Paper.

Plate II.

RELATION TO

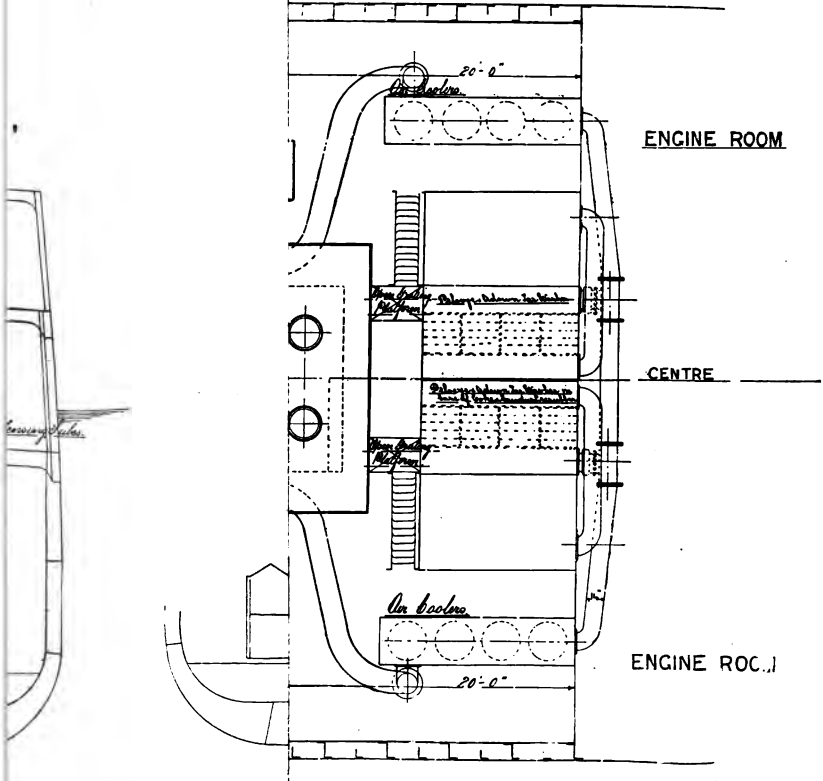

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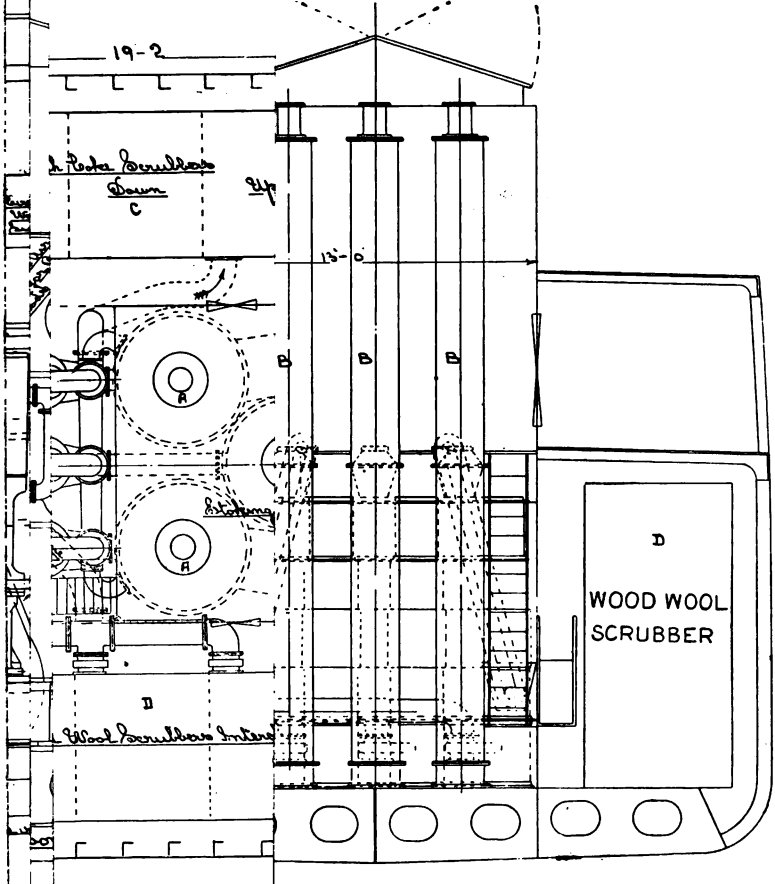
Plate III.



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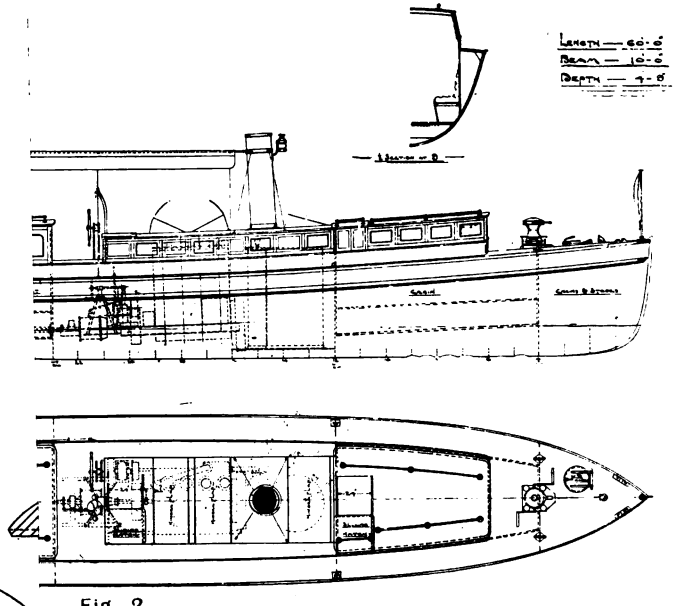

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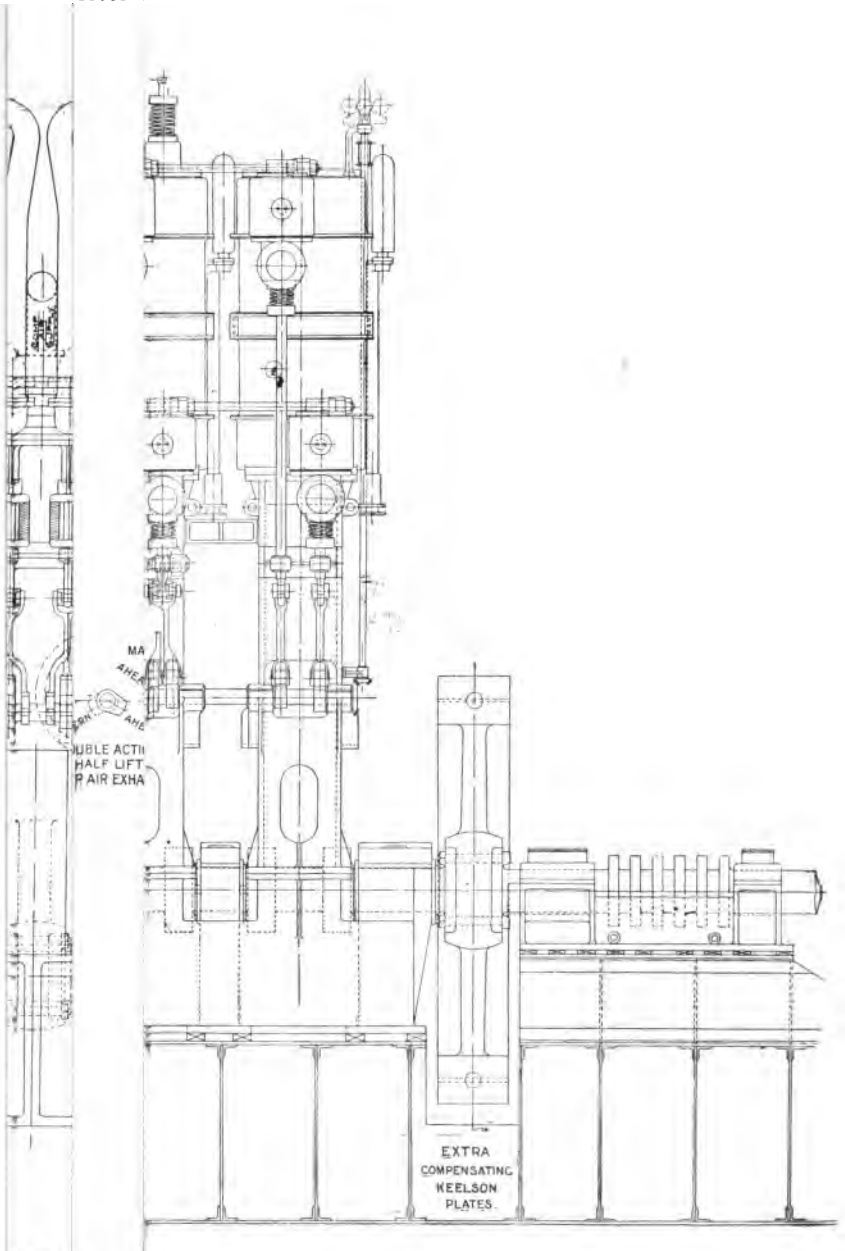

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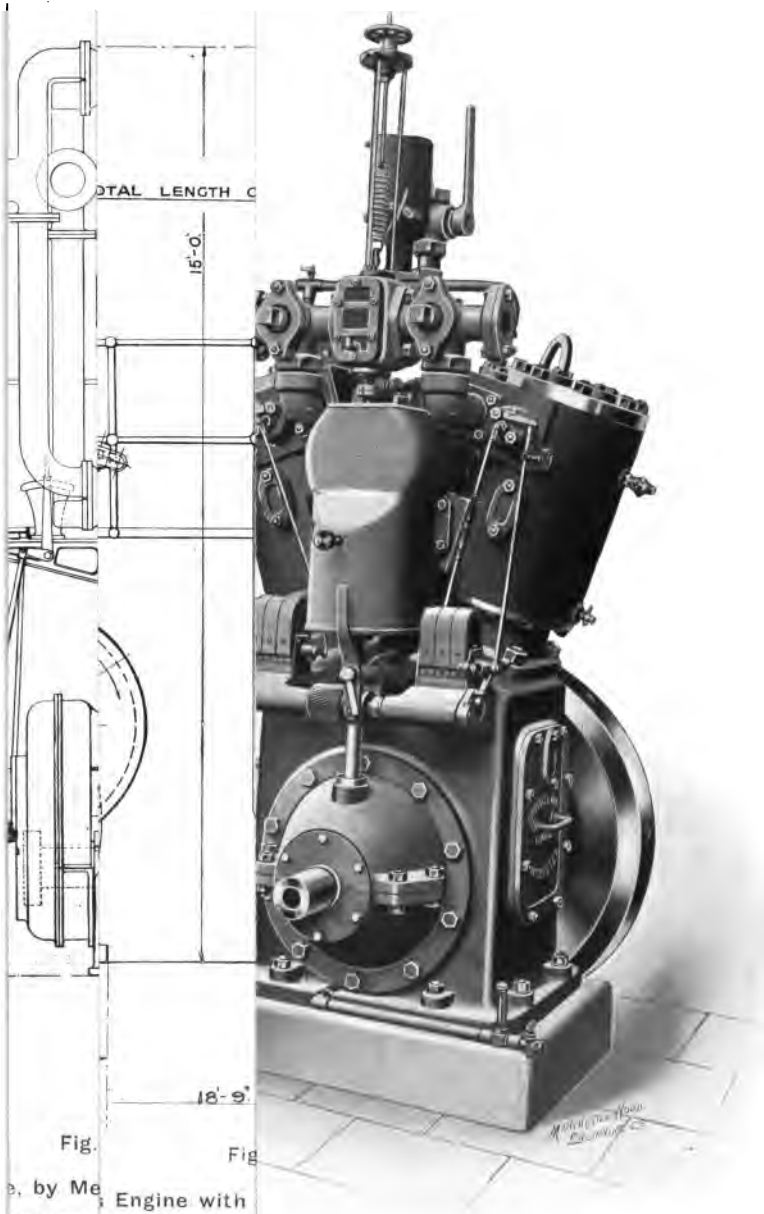

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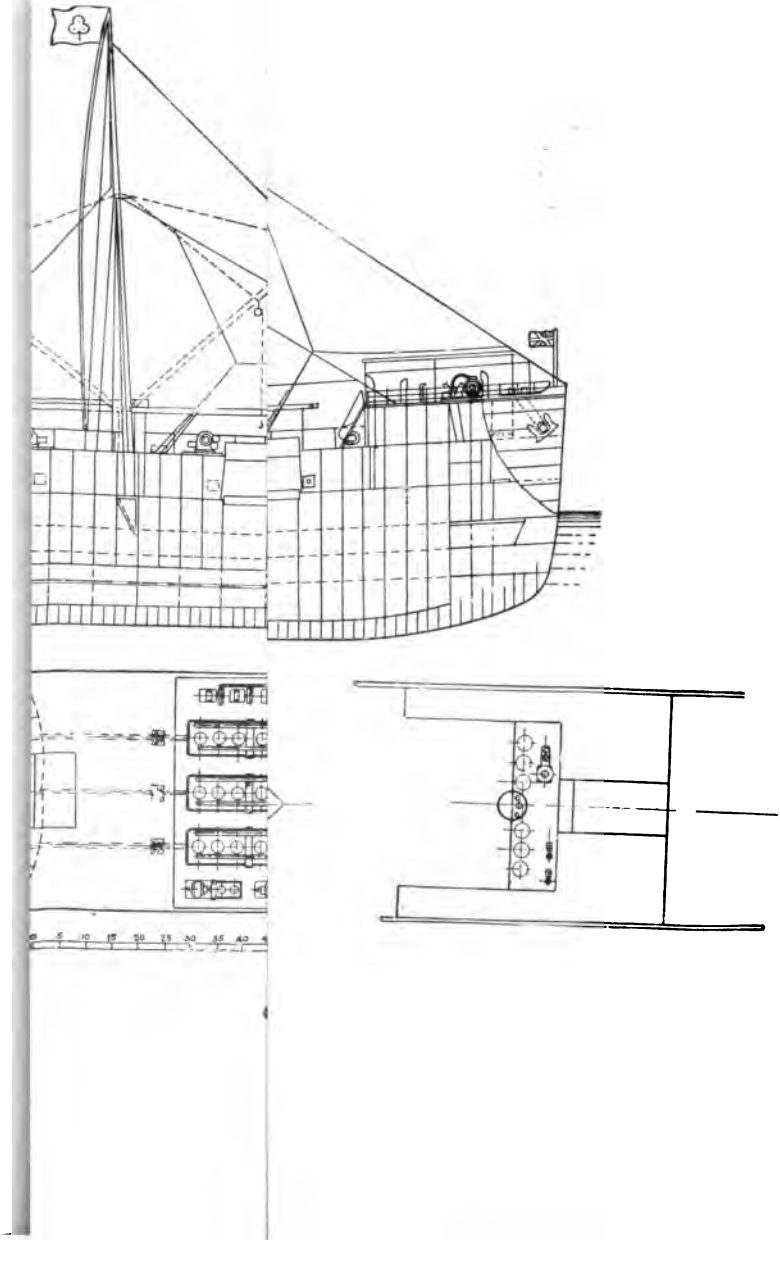

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MECHANICAL DRAUGHT FOR STEAM BOILERS AND FLUE GAS ANALYSIS.

READ SATURDAY, 9TH MARCH, 1907,

BY

Mr. J. CRAWFORD, M.I.Mech.E.,

MANCHESTER.

As far back as 1830 when steam navigation was in its early stages it was found advantageous to apply a system of mechanical draught to obviate the necessity for lofty chimneys of large sectional area. The advantages to be derived forced themselves on marine engineers at that early date, when various systems were applied with more or less success. Its general application was slow owing to the workmanship of the boiler not being sufficiently good to resist the effects of forced combustion.

About the year 1870, Mr. D. K. Clark verified the advantages of a "rapid or rather intense draught in perfecting combustion and extinguishing smoke," but in reference to this, Mr. C. Wye Williams remarked that "the difficulty lies in the obtaining of the intense draught."

In 1885 Mr. Howden patented his heated air system in conjunction with forced draught, produced by steel-plate fans placed in a convenient part of the engine-room or stokehole.

Immediately after this engineers began to recognise the many objections to the forced draught system, particularly the danger to firemen through furnace explosions and "blow-back" due to the limited area through flues, tubes and uptakes. These objectionable features no doubt prompted the next move in getting out a system of draught in every way similar to

chimney draught, only of greater intensity and which is now generally known as "induced draught." In 1891 The Ellis & Eaves (patent) system was introduced which embodied all the advantages of natural and induced draught, with the economy to be gained by heating the air before entering the furnace. This was accomplished by placing a fan at the base of the funnel with an air heater in the uptake *through* the tubes of which the gases of combustion passed on their way to the fan, the air to support combustion at the same time passing *over* the tubes and being collected by a steel-plate casing to direct its course to the furnace. This combination gives highly efficient results, for not only is the air heated, whereby a more perfect combustion is obtained, but a larger amount of the heat that would otherwise go to waste and pass into the atmosphere, is reclaimed and returned to the furnace.

In the same year in a "review of engineering during the past decade" published in the proceedings of the Institution of Mechanical Engineers, Mr. Alfred Blechynden dealt with the subject as follows:—

"First, it seems fairly well established that if the boilers are well constructed and are provided with ample room to insure circulation, their steaming power may without injury be increased to about 30 to 40% over that obtained on natural draught for continuous working, and may be doubled for short runs.

"Secondly, the same or even a greater power being indicated, it may, with moderate assistance of mechanical draught be developed with a smaller expenditure of fuel, the grates, etc., being properly proportioned.

"Thirdly, mechanical draught enables an inferior fuel to be used; and

"Fourthly, under certain conditions of weather, when with normal proportions of boiler it would be impossible to maintain

steam with natural draught, the normal power may with mechanical draught be ensured. In particular cases any or all of these advantages may be a source of economy; and the first of them may render possible what would otherwise be impracticable."

Having referred to and quoted disinterested authors as to the benefits of mechanical draught for marine boilers, we may now consider what are the essential requirements of a good system of draught for land boilers in relation to ordinary chimney draught.

The power and energy required to drive manufactories and electric generating stations throughout the country is stored in fuel, therefore the selection of this, and the most effective method of consumption is of vital importance in running a works on the most profitable basis.

In view of trade competition the up-to-date manufacturer is willing to consider any suggestion or appliance that will give higher efficiency or better economy. Mechanical draught is therefore rapidly changing the ordinary methods and has now placed the manufacturer in a position to select his fuel on the basis of cost and calorific value only, knowing that his mechanical draught will deal with the other points that, previous to its adoption, required careful consideration.

In order that mechanical draught may be fully understood, it is primarily necessary to have a clear idea of what is meant by natural or chimney draught. Natural draught is the movement of air produced by the difference in density due to temperature. To utilise this principle in producing draught to aid in the combustion of coal, chimneys are built. The chimney is designed to encase a column of the heated gases of combustion, the only opening being that at the top to allow for the escape of the heated gases, and that at the bottom for the entrance of cold air. The cold air really enters at the

ashpit, which for the sake of clearness may be considered as the bottom of the chimney. It follows from this definition of the function of a chimney that the intensity of the draught produced increases with the rise in temperature of the gases of combustion, and vice-versa.

Chimney draught is therefore caused by the density of a column of the outer air being greater than the density of a column of equal height of the hot gases encased by the chimney. The fire in the furnace leading to the flue circuit or at the base of the chimney, causes the action to be continuous, and thus promotes combustion, producing heat, a certain quantity of which may be employed for the generating of steam, the remainder being used to keep the draught continuous. The following example will serve to show more clearly how the draught is produced. It is found that when a gas at a temperature of 32° Fah. is heated, it increases $\frac{1}{491}$ of its original volume for every rise in temperature of 1° Fah. Therefore if a gas is heated through 491° Fah. its volume will be doubled, and hence its density will be half the original density. If the gases in a chimney are heated through 491° Fah. the density of the outer air will be double the density of these gases, and hence the pressure to force air through the fire will be double the pressure exerted by the heated gases in the chimney.

A chimney in itself has no power of suction. The sole reason for the action is the fact that the external air is heavier than the heated gases in the chimney, and therefore, forcing its way into the chimney through every available opening, displaces the lighter gases.

As the draught is caused by the difference in density due to increase in temperature in one of two columns of gas equal in height, it follows that the sectional area being the same, a high chimney will give the best draught.

The intensity of the draught produced by a chimney of ample area will never vary except in so far as it is affected by heat or external causes due to atmospheric conditions. Thus a rise in temperature inside, or a fall in temperature outside, will increase the power of the draught, and vice-versa.

The density of water vapour is not more than about half that of dry air, hence in foggy weather the atmosphere which then consists largely of water vapour is less dense, and consequently the intensity of the draught is diminished.

Upon the intensity of the draught depends the amount of fuel which it is possible to burn upon a given area of grate. With a chimney 300ft. high having a sectional area equal to $\frac{1}{8}$ of the working fire grate, and flues in the same proportion, 25lbs. of hard coal can be consumed per square foot of grate per hour.

Economy depends closely upon the draught and upon the amount of fuel consumed. If the draught is bad, the fuel has to be spread in thin layers upon the grates, and in consequence large volumes of air pass through the fuel without combining with the carbon. This uncombined air is not only useless, but it is also harmful, as it lowers the temperature of the fires in passing through, cools the flue gases below the normal temperature, causes leakage of boiler seams, and still further diminishes the intensity of the draught by overloading the chimney. The evil is therefore increased instead of being diminished.

In electric generating stations the load often changes rapidly and to a very large extent. Fog and sudden darkness are the usual causes of rapid fluctuations in the load. This fluctuation is serious, as not only does the demand for light rapidly reach a maximum, but the intensity of the draught is diminished, preventing the rapid combustion of the fuel at the time when it is most necessary. Hence the application of mechanical

draught, as distinguished from ordinary chimney draught becomes an important factor. These remarks apply more or less to all boiler installations.

Induced Draught Fan.

Mechanical Draught is rendered more powerful by other means than a chimney. An ordinary locomotive may be given as an example of assisted draught. The chimney being very low and of small sectional area there is practically no natural draught, and this deficiency has to be remedied by other means. This is done by a jet of live steam, or by the exhaust steam from the engine, which forces the products of combustion through the chimney.

By using a draught of this kind coal can be burnt at the rate of 80 to 140lbs. per square foot of grate area per hour. It is not necessary to spread the fuel in thin layers, as the intensity of the draught is sufficient to overcome the resistance of a thick fire, and to ensure the almost complete combination of the air with the carbon whilst passing through the fire. By working the fire thick it acts as a resistance and reduces the

volume of air, a higher temperature is produced in the furnace and economy is the result.

When an ordinary chimney draught is used, for every pound of coal burnt about 24lbs. of air pass through the furnace. Of the 24lbs. 11 or 12 combine chemically with the pound of fuel, and the remaining air passes into the chimney.

From the foregoing it is clear that the primary object is to get complete combustion of the fuel, with the least possible excess of air beyond that required for actual combination with the constituents of the fuel. Every pound of air beyond that quantity is a loss. The boiler is thus deprived of so many heat units required to raise its temperature to that of the escaping gases, and which pass into the chimney without doing any useful work.

In this respect the advantages of mechanical draught are apparent.

Professor Rankin in "The Steam Engine and other Prime Movers" remarks, "with mechanical draught there is less air required for dilution, consequently a higher temperature of the fire, consequently a more rapid conduction of heat through the heating surfaces, consequently a better economy of heat than there is with chimney draught."

The reasons for this are not far to seek. In the first place, the fires can be worked very much thicker than with natural draught, with the result that the air has further to travel through the incandescent fuel, and therefore more time in which to give up its oxygen; and in the second place, the very intensity of the draught through the incandescent fuel causes a more intimate mixing of the oxygen with the carbon than would be possible with chimney draught.

Almost all coals, more or less, but especially bituminous coals, give off large volumes of what are known as hydrocarbon gases. They are a chemical compound of carbon and hydrogen

in varying proportions, the heavy hydrocarbons, or those having a large amount of carbon, requiring a comparatively high temperature for their combustion. It is in dealing with these gases that the advantage of a high temperature in the furnace is so great.

If these gases are supplied with an excess of cold air, they burn, usually with a more or less smoky flame; on the other hand, if insufficient air is admitted, or if they become cooled below a temperature of about 1,000° Fah., owing to the proximity of the conducting surfaces of the boiler, they in either case become extinguished and pass away unconsumed, partly in the form of black smoke, and partly as gas. In many cases the carbons become re-ignited on leaving the boiler. This re-ignition is known as "flaming," and is a serious evil often attending the use of bituminous coal with bad draught. The heat produced in this case is entirely lost, and only tends to heat the flues, and where chimneys are short causes flame at the top.

It is in dealing with these gases that the great advantage to be derived from mechanical draught is obtained, as it enables an ample supply of air to be introduced through the fuel, sufficient for the perfect combustion of all the hydrocarbon gases without at the same time lowering their temperature, as would be the case if an excess of cold air were admitted through a thin fire. From this it is seen that the gain in economy must be very marked when mechanical draught is used in conjunction with heated air.

In the first place less air is required per pound of coal on account of the more intimate mixture which takes place between the fuel and the oxygen of the air.

Secondly, by heating the air, not only is a certain amount of heat abstracted from the waste gases, which would otherwise pass up the chimney without any beneficial effect, but the

introduction of the heated air into the furnace enables a perfect combustion of the gases to take place in the furnace or combustion chamber, before leaving the boiler. More of the heat in the fuel is thus utilised in making steam, whilst flaming and the formation of black smoke is prevented, with a smaller amount of air than would be necessary with thin fires and chimney draught.

The temperature in the furnace may be 2,600° Fah., and that in the chimney 650° Fah., so that one-fourth of the heat produced passes into the atmosphere. If the amount of air passing through the fire could be reduced to 11·5lbs., that is to say, to the chemical minimum, and the temperature kept the same, complete combustion would still take place, but only one half the amount of heat would pass into the chimney, the result of which would be an economy of one-eighth of the fuel.

With mechanical draught and thick fires it is found that the temperature of a chimney is less, and also that less gas escapes by the chimney; therefore, the economy is really greater than one-eighth of the total coal consumption.

In practice the determination of the air supply is based upon the percentage of carbon contained in the coal.

The carbon present in the various grades of coal may vary considerably; ranging from about 50% to 87% in bituminous, and as high as 90% in the best classes of Welsh and Anthracite coal.

The product of perfect combustion of carbon (C) is carbon dioxide (CO_2) formed by the chemical combination of two atoms of oxygen (O) with one of carbon; if combustion is incomplete then only one atom of oxygen combines with the carbon, the product being carbon monoxide (CO).

The following will demonstrate the necessity of regulation of the air supply, and the process of combustion taking place within the furnace :—

When coal is thrown into the furnace it is subjected to the high temperature existing therein, a chemical process takes place, and inflammable hydrocarbon gases are immediately given off; owing to the presence of oxygen in the surrounding air, these gases are ignited and burnt, forming carbon dioxide.

In addition to the calculated volume of air necessary for combustion, an additional volume must in practice be provided for dilution; *i.e.*, to secure the intimate contact of the air at all parts with the glowing fuel.

The constructional limitation of the furnace, and the more or less uneven distribution of the fuel on the grate make this course necessary.

If an insufficient supply of air is present, only a corresponding proportion of the hydrocarbon is ignited, and the resulting carbon dioxide mingles with the hot unconsumed gases, to which it immediately yields one atom of oxygen; thus the final product becomes carbon monoxide. The process of combustion is then incomplete, and smoke, more or less dense, indicates its presence and consequent loss of efficiency.

If, on the other hand, the volume of air admitted to the furnace be sufficient to ensure combustion, owing to the excess necessary for dilution, as above stated, a direct loss of heat occurs. The excess of air admitted at atmospheric temperature rapidly absorbs heat from the gases, and as the heat extraction from the heating surface of the boiler depends directly upon the difference in temperature between the products of combustion and the water, and as the temperature of these products is decreased owing to the excess volume of air, it follows that the efficiency of the heating surface is reduced, and that a high proportion of heat is consequently carried to waste by the flue gases. This is due in a great measure to the escape of hydrogen which requires a very high temperature for its complete combustion, and when consumed produces 58,340 British

Thermal Units per pound, the B.Th.U. as usually expressed, being the amount of heat required to raise one pound of water 1° Fah.

In order to appreciate fully the detrimental effect which incomplete combustion may have upon fuel economy, it is necessary to examine the conditions of temperature which may be expected within the furnace when the process of combustion is complete, and when only partial combustion takes place owing to insufficient air supply.

When one pound of carbon is burnt to CO_2 (carbon dioxide) 14,650 British Thermal Units of heat are liberated during the process, but if combustion is imperfect and CO (carbon monoxide) formed, then only 4,400 B.T.U. are given out, Therefore the loss due to incomplete combustion of one pound of carbon is 14,650 − 4,400 = 10,250 B.T.U. These figures of course refer to extreme limits.

Incidentally, we see how greatly detrimental to economy an insufficient air supply must be, and how great is the loss in efficiency of the steam plant due to the action of an over-taxed chimney.

The atomic weights of carbon and oxygen are respectively C=12 O=16; hence, as the result of perfect combustion is CO_2 we find that to burn one pound of carbon $\frac{16 \times 2}{12} = 2{\cdot}66$lbs. of oxygen are necessary. Oxygen, however, is contained in air only to the extent of 0·236 per lb. Therefore the total weight of air required is $\frac{2{\cdot}66}{0{\cdot}236} = 11{\cdot}3$lbs.

If we consider an average coal containing about 75 % weight of carbon, we find that between 13 and 14lbs. of air are approximately necessary for the complete combustion of one pound.

Owing to the composition of air, the burnt gases will contain about 75 % of nitrogen.

If we multiply the weights of the products of combustion of one pound of carbon, and of the attendant nitrogen by their respective specific heats, we find that approximately 2·90 B.Th.U. are required to raise the temperature of the gases through 1° Fah. As we have already seen, the heat evolved by perfect combustion is 14,650 B.Th.U., therefore the theoretical temperature resulting from the combustion of one pound of carbon will be $\frac{14,650}{2·9} = 5,050°$ Fah.

In practice, the temperature in the fire resulting from the combustion of a high grade fuel on the grate with an excess air volume, so determined as to give thorough dilution, will be found to average about 2,500° Fah. only.

If, however, we imagine the case in which a very imperfect process of combustion occurs, due to bad draught and the absence of a sufficient supply of oxygen, and substitute corresponding values in the above ratio, we can see clearly that we should arrive at a temperature very much lower than the theoretical temperature resulting from perfect combustion, and that, consequently, the average temperature of the fuel bed under these conditions would be greatly decreased.

To study the actual results obtained with regard to efficiency of combustion of fuel with a given percentage of carbon, it is essential to determine the composition of the flue gases, particularly to learn the percentage of CO_2 and CO contained, and to note the ratio of air supply to fuel.

The latter may vary in practice very considerably, and in the utilisation of the various grades of fuel it is of the utmost importance to view clearly their relation to the above named percentages.

Therefore, before going further, it is desirable to deviate and investigate the method of controlling the composition of the flue gases.

For portable use and periodical testing a very useful appliance for the analysis of flue gases is that shown in the illustration, Fig. 1.

Fig. 1.—Orsat set for testing Flue Gases.

The apparatus consists of a measuring tube A, graduated into 100 c.c., the lower part being subdivided into $\frac{1}{5}$ c.c. This tube which is surrounded by a water-jacket for the maintenance of a constant temperature, is connected at the bottom by means of rubber tubing with the levelling bottle B, which should be about two-thirds filled with water.

The upper capillary end of A is connected by means of rubber tubing to one end of the capillary tube C, which is furnished with a series of stopcocks. The three tubes carrying stopcocks E, E_1, E_2, are connected by means of rubber tubing with the absorption pipettes F, F_1 and F_2. These pipettes are U shaped vessels, having the compartments attached to the stopcocks filled with thin-walled glass tubes for the purpose of exposing a large surface of the absorbent when gas is admitted. The pipettes are filled with such absorbent liquids as are required by the gas which is to be analysed. At D is a three-way stopcock.

For the analysis of chimney and furnace gases, F should be filled with the caustic potash solution for carbon dioxide (CO_2), F_1 with pyrogallate of potash for oxygen (O); and F_2 with a strong solution of cuprous chloride in hydrochloric acid for absorption of carbonic oxide (carbon monoxide) (CO).

In order to protect the re-agents from the action of the atmosphere the open limbs of the pipettes may be connected by means of rubber tubing with a water seal apparatus; (not shown in the sketch).

The side opening of stopcock D is used for displacing the air, etc., in connecting tubes by means of the rubber aspirator G. If necessary to filter the gases a U tube, loosely filled with cotton wool, at the entering end of tube C is used.

Manipulation:—Displace the air in connecting tubes by means of the indiarubber aspirator G placed in connection with the side opening of stopcock D; then fill measuring tube A with the gas to be analysed, place the levelling bottle B on the top of the case, and turn stopcock D at right angles to the long inlet tube to which it is attached so as to put the measuring tube in connection with the atmosphere. As soon as the water reaches the 100 c.c. mark at top of A (it should never enter the capillary C), cut off the communication at D by turning the tap.

Turn stopcock D so as to put gas supply in communication with the measuring tube A, lower levelling bottle B until the gas fills the tube to a little below the zero graduation, and then close the stopcock D.

Now raise the levelling bottle B until the gas is compressed and the water rises in the measuring tube to a little above the zero graduation. Put a pinchcock on the indiarubber connecting tube, place the levelling bottle on the working bench, and cautiously open the pinchcock until the bottom of the water meniscus just touches the zero graduation. Then momentarily open stockcock D, and there remains exactly 100 c.c. of the gas at the prevailing atmospheric pressure.

To analyse the gas place the levelling bottle B on top of case, open the cock E, and the gas will pass into the absorbing pipette F. When it has all passed in, lower the levelling bottle B until the absorbing liquid in F nearly reaches the stopcock E, then put B again on the top of the case to force gas once more into the pipette F. Now cautiously lower the levelling bottle B with the right hand, and shut the stopcock E with the left as soon as the absorbent reaches its under side. Upon holding the levelling bottle B so that the water in both A and B are at the same level, the diminution in volume of the gas may be read off. Repeat the passage of the gas into the pipette until a constant reading is got; this represents the percentage of that constituent of the gas analysed, which can be absorbed by the liquid in F. The gas is then similarly passed into the absorbing vessels F_1 and F_2 the diminution in each case represents the volume of gas absorbed.

These investigations can readily be made with sufficient accuracy by any intelligent person after a few trials.

For permanent purposes, and to assist the firemen in getting the most economical results, and also to check neglect on their part, it is absolutely necessary to have a self-registering

apparatus which automatically and continuously gives a daily record of the efficiency of combustion (see Fig. 2).

Fig. 2.—Flue Gas continuous Testing Set.

The combustion recorder, as illustrated, is unique and specially designed for this purpose. Its action is automatic

and continuous, and produces a chart showing at any time the waste, or otherwise, taking place in the furnace. It also shows at the same time and on the same chart the strength and variation in the draught, and its effect on the efficiency of combustion.

Its working is based on the well-known fact that a solution of caustic potash (specific gravity 1·27) absorbs carbon dioxide.

A quantity of the flue gases is automatically drawn or forced through the Recorder, part of which is bottled up, measured and passed through the solution. The quantity of gas absorbed, representing the percentage of CO_2, is determined and recorded on a diagram by means of lines. This process is repeated about every three or five minutes. The bottoms of the various lines form a curve which shows the fluctuation of the percentage of CO_2 during the time the recorder has been working.

It is advisable to have the recorder so arranged that analysis from one or any number of furnaces may be made at one time, therefore it is desirable to have a common collecting pipe running the full length of the battery of boilers, and a branch pipe with stop cock joining up to each side flue.

An intelligent stoker will find the recorder of great assistance to him in getting the maximum effect out of the boilers with the least possible quantity of fuel, because a close supervision of the diagram will enable him to regulate the draught and thickness of fires to a nicety.

It is often found when analysing the gases of mechanically and hand fired furnaces that the amount of CO_2 is as low as 6%, and even less, whilst it might have been kept constantly at 13% and more, if the men in attendance had been assisted by a recorder.

Considering that about 16% more coal is consumed if the percentage of CO_2 is 6%, instead of 13%, the waste will be

equal to 160 tons a year, assuming that the total quantity consumed during the year is 1,000 tons.

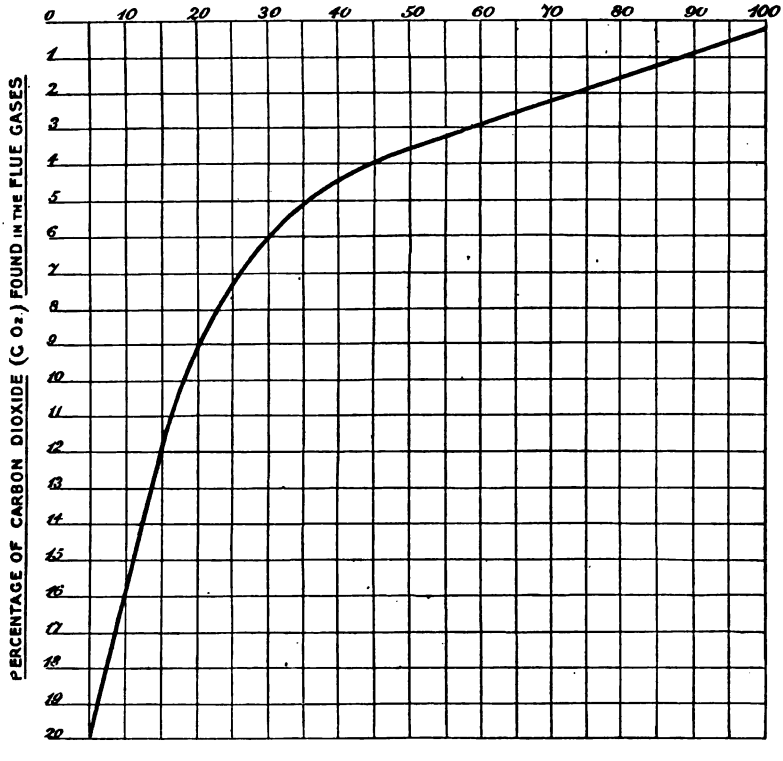
It is therefore clear that the initial cost of putting up recorders will be paid within a very short time by the saving in fuel, and that a very substantial profit will be effected by their continuous use.

The solution for the recorder is got by mixing 395 parts by weight of caustic potash with 875 parts by weight of distilled water, and has then a specific gravity of 1·27.

It is of importance to note in this connection, that the recorder automatically produces a chart, which is always visible while on the instrument, thus enabling an engineer to turn the information which the instrument supplies to account immediately, without having to wait until the chart is taken off, or having to first prepare the same by washing, etc.

Furnace gases before leaving the boiler can never be cooled to the temperature of the boiler which they heat. In order to extract the heat from these gases as much as possible economiser pipes are used whereby the feed water is raised in temperature, or air heating apparatus may be used and the heated air returned to the furnace or utilised for heating, ventilating, and drying purposes. These pipes filled with water or air at a lower temperature than the water in the boiler are placed beyond the boiler so that they may absorb heat from the passing gases. The temperature of the boiler water may be 350° Fah. and that of the chimney 650° Fah. If the economisers have feed water entering at 110° Fah. they may cool the passing flue gases to 350° Fah. thereby saving the heat represented by the difference in temperature, namely 300° Fah. It has been found that appliances such as these are most economical, but at the same time they obstruct the flow of gases to some extent, and further diminish the draught by extracting their heat. By using superheaters and a series of the economisers filled with

Diagram Showing Efficiency of Combustion.



NOTE :—To find by analysis the percentage of carbon-dioxide (CO_2) in gases of combustion is of equal importance to indicating the engines for power and steam consumption.

successively colder and colder water, and finally an air heating plant, it is possible to cool the gases to such an extent that practically no draught would be produced by a chimney.

Where this is practicable the draught is produced by forcing air into the furnace by mechanical means or drawing it out by induction, thus mechanically passing the hot gases of combustion through the superheaters, economisers, or other cooling

device before delivery into the atmosphere, the chimney being useless except as a means for conveying the gases clear of the surrounding buildings.

FOR MECHANICAL DRAUGHT A FAN IS THE BEST APPLIANCE.

Therefore in considering economy it is necessary to compare the original cost of a high chinmey with that of a fan and low iron stack, and also the cost of working the chimney with the cost of working the fan. There is also to be considered the cost of the apparatus used to cool the gases in order that the economy due to the abstraction of their heat may be secured.

It has been shown that chimney draught absorbs about one-fourth of the total power of the boiler. In a boiler plant of 2,000 HP there may be 1,500 HP developed at the engine, and the remaining 500 HP absorbed by the chimney. Thus, it costs 500 HP to produce a draught for 1,500 HP nett. If a fan and sufficient economiser pipes are used, the amount of *excess* of air may be reduced from 12 to 6lbs. There will then be 18lbs. of air entering the chimney per pound of fuel instead of the usual 24lbs., that is, there will be an economy of 125 HP Of the 375 HP still going to waste at 650° Fah. another 125 HP may still be saved by the use of economiser pipes or other heat absorbing apparatus. Altogether there will be an economy of 250 HP representing a final flue temperature of approximately 300° Fah. and this admits of further economy by extending the heat extraction appliances.

The power absorbed by a well designed and *correctly applied* fan is about 1% of the total power of the engine supplied by the boilers. Thus, in the case under consideration, the fan will absord about 15 HP, therefore, the nett saving will be 235 HP, that is, about 16%. Even if no heat absorbing apparatus is used the first 125 HP saved by the fan may be relied upon. This follows from the fact that the fuel has not to

be spread in thin layers, and that *less excess* of air is required. The 18lbs. of air referred to is not the lowest figure possible. It has been found that with a good draught and thick fires the air supply may be reduced to less than 15lbs. per lb. of fuel.

M. Bertin, in his book "Chaudieres Marines" Paris, 1896 says: "Owing to the perfection of the chemical combination with less excess air the temperature in the furnace is increased and the shortening of the flame gives it less opportunity to cool down prematurely before passing over the effective heating surface."

With mechanical draught increased efficiency of service is also rendered possible. When there is a sudden demand for steam the fires which have been rather low may be made to burn vigourously by simply opening the damper or increasing the speed of the fan; then, as soon as the increased demand for steam has passed, the output may be reduced to a minimum almost at once.

From steam boilers with a low rate of combustion per square foot of grate surface, it is possible to obtain very economical results, and at the same time to largely increase the rate of combustion without loss, and in most cases with considerable gain. As already stated, if the draught is poor, the fuel has to be spread in thin layers and an excess of air passes through. When the draught is more intense it is possible to keep brisk combustion and at the same time have a full fire. By doing this, combustion is effected with the use of very much less air than is the case with a poor draught.

"Generally, it may be taken that there is greatest economy in working when that fuel thickness is used which is the greatest possible with the available draught without excessive stirring of the fire."

When this maximum thickness has been found, the grate area is then cut down to that necessary to burn fuel sufficient

for the production of the steam required, leaving of course a margin of draught available to be used when there is a sudden demand for extra steam.

These results can only be obtained by the aid of mechanical draught. The steam jet may be left out of the question as a draught producer, for although it may be cheaply applied, it is costly to work, using in many instances as much as 12% of the total steam generated. Steam jet furnaces, however show an economy because cheap fuel can be used with them, and the jet may thus save more than it costs.

For boiler draught the design of fan should be simple in construction, and arranged to run at a low speed of revolution. As the fan revolves the vanes carry air round with them, and as this air tends to move in a straight line it will leave the fan tangentially at any opening available.

More air to take its place enters at the fan inlet, and also in its turn escapes tangentially with a velocity approximately equal to the peripheral speed. It follows from this that the tip of a fan blade must move at such a speed as will produce the velocity in the movement of the air that would be given by a draught of the intensity required.

Say that the draught required is to have an intensity equal to 1in. water gauge. The laws governing the flow of gases are the same as those for liquids. The velocity of flow depends upon the height of the column equal to the pressure. Therefore, at ordinary atmospheric pressure and temperature, the pressure on a square foot is 2,115lbs. One cubic foot of air weighs 0·0778lbs. at 52° Fah. Hence, if a column of air at atmospheric pressure is of equal density throughout it must have a height of 2,115 ÷ 0·0778 = 27,160ft. The formula for the flow of a fluid is $v = \sqrt{2\,g\,h}$; where v equals the velocity of a body in feet per second, h is the height in feet from which the body has

fallen, g is 32·2 and represents the effect or acceleration due to gravity in England.

Therefore a column of air would flow into a vacuum at a velocity per second equal to $\sqrt{64 \times 27{,}160}$ or about 1,320ft. per second. A pressure of 1in. water is equal to 0·578 of an ounce per square inch.

An atmosphere of pressure is 235 ounces per square inch therefore it follows that 0·578 ounce is $\frac{1}{407}$ of an atmosphere or say 66 feet. The velocity due to a head of 66 feet is thus $\sqrt{64 \times 66}$, or about 65 feet per second. When a chimney draught is used a flow of 30ft. per second is considered as a minimum for smoke prevention, double this would therefore be a very good draught.

As a rule the formula used for draught velocity is 65·5 H where H is the water gauge produced in inches.

The power to drive a fan increases as the cube of the velocity. Therefore for economical working, the speed of a fan must not exceed that necessary to produce the required draught. In other words, *it is very wasteful of power to use a small fan driven at a high speed of revolution in order to deal with a volume of air beyond its capacity.* It is therefore desirable, from an economical point of view, to employ a fan of sufficient size to work with the volume of air required at the lowest speed consistent with the duty required from the boilers. The fan tip must revolve only at such a velocity as will produce the necessary draught.

There are three ways of using artificial draught produced by fans, namely, the closed stoke hole ; the closed ashpit ; and the induced system. In the closed stoke hole the boilers are placed in an air-tight chamber. Air is forced into this chamber by means of a fan, and then passes through the furnaces in which

the heat is very intense owing to the strength of the draught. This system is rarely used except for ship's boilers.

In the closed ashpit system, air is blown below the grates and sometimes a portion admitted above the fuel, with this system care must be taken, when opening doors, that the flame does not blow out through the fire-door, which often occurs where there are contracted flues or a small chimney.

For land purposes the third or *induced draught* system is generally preferred and is more applicable. The fan draws the waste gases from the boilers, and where the flues are small accelerates their flow towards the chimney, and thence into the atmosphere. This kind of fan draught is more powerful than any chimney draught, and has the advantage that its intensity may be increased or decreased almost simultaneously with the increase or decrease in the demand for steam.

The fact that mechanical draught is able to meet the fluctuating demand for steam is not the only advantage pertaining to it.

The increasing of the steaming capacities of the boiler plant which already exists, is one of its most useful applications. The boiler plant may have outgrown its original limits, and be beyond the capacity of the chimney. In a case like this the draught will be bad and sluggish. By using a fan this is remedied at once, the fires are brightened, and one out of every three of the boilers may be put out of use for cleaning or other purposes.

The lower the temperature of the chimney gases the better will be the action of the fan. When using ordinary chimney draught, if the economiser surface is increased it will mean that the draught is decreased, because the chimney gases will fall in temperature, whereas, with mechanical draught the action of the fan is improved, the draught intensified, and the full efficiency of the economiser and boiler plant is realised.

Great economy may be effected by using cheaper fuel. Coal that is sold for perhaps half the price of the so-called best quality often contains three-fourths or more of its calorific value. By using fan draught this fact may be taken advantage of, and in this way what is perhaps the greatest of economies may be secured. Small coal in many instances is equally as good as larger coal in heating capacity, but it requires such a powerful draught to burn efficiently that it commands a lower price.

In addition to economy of fuel there is another great advantage in the use of a fan. In a new plant it is often quite impossible to say how large a plant, chimney, etc., may ultimately be required. Thus, the chimney may be built either very much too large, in which case there is the risk of it never being required, or else so small that in a year or two it will be practically useless, as every boiler added will reduce the already poor draught. A second chimney has then to be built, involving heavy expenditure.

If however, a fan had been used with a small iron stack at the beginning, when more power is required the fan could be increased in speed, or it might be sold and a new one put in of larger capacity. A masonry chimney cannot be sold separately, nor can it be enlarged in diameter, and very little is gained in raising it in height.

The many important advantages of a good draught on the combustion of fuel are already well known to engineers, amongst whom it is a general and recognised axiom that a good draught means both good efficiency and steaming capacity, as well as economy in fuel, relative to the quantity of steam produced.

The fan is the vital portion of an up-to-date mechanical draught system, and on its efficiency, proportion, and proper application depends the success of the plant. The experience

necessary to deal with these points successfully, and without experimenting, is only obtained by years of practical application and an engineering knowledge of all the probable conditions likely to effect the operations of the fan.

It is found that the fans best suited for induced boiler draught are those revolving at a slow speed in a steel plate casing. Small high speed fans should be avoided except where economy of space and weight demand their use. The inlet may be at one or both sides of the fan, preferably on both sides, and with double bearings to avoid any overhang of the working parts, and the outlet arranged to suit existing flues or position of chimney.

The fan should be as simple as possible in mechanical construction, with strong plates well stiffened by angle and tee iron, and with self-oiling bearings, jacketted for water circulation. The shaft should be turned perfectly true (not rolled or ground), of large diameter, and arranged to run in long bearings. The Runner, or fan wheel, must be in perfect balance under working conditions, otherwise vibration may cause deterioration and damage.

The rotary member of the fan should be practically indestructible, designed to resist unequal expansion, contraction, and the sand blast action, which causes breakdowns and repeated renewals of flimsy structure.

The fan should have a margin of capacity and discharge into connection with easy bends, if any, and without sudden changes in area.

DISCUSSION.

Mr. C. E. STROMEYER said no mention was made of the necessity of having air over the fuel; it was well-known that this was one of the essentials of good combustion and smokelessness; if no air was passing over the fuel when the combustion of smoky fuel was taking place, there would be smoke and also a large waste of heat. In fact, he did not think the views put forth by the author respecting the combustion were quite in agreement with scientific views on the matter. Mr. Crawford had mentioned that when the carbonic acid had been formed and came in contact with the unburnt hydro-carbons, the oxygen was given up to the hydro-carbons, and carbonic oxide was formed; but all experiments he (Mr. Stromeyer) was acquainted with, showed that when the air first came in contact with hot coal carbonic acid was formed, and if that carbonic acid passed through red hot fuel it was converted into carbonic oxide, and unless air was admitted while hot, it passed away up the chimney as carbonic oxide, and did not, he thought, interfere in any way with the hydro-carbons, which are produced by distillation.

Mention had been made as to the different methods of analysing flue gases. As he had taken some interest in this matter, he thought a few notes on the subject would be of interest. He had found that long india-rubber tubing allowed carbonic acid to pass out very freely, and in experiments made on the analysis of gasses care should be taken to have all the india-rubber tubing as short as possible, as otherwise a very large amount of carbonic acid would escape and the loss would influence the analysis.

It was also very essential for accurate work, not to carry out the analysis by the method suggested in the paper, *i.e.* simply drawing the gases out of the flue into the Orsat apparatus; they should first be led into a nasometer, so that a continuous record could be obtained of what the boiler was doing. One gasometer about 18in. high could be filled in about half-an-hour, and during the time it was being filled another one could be analysed. By the adoption of that method he had been able to get a very continuous record of the analyses of the flue gases, and found that it was in agreement with the chemical analyses of the fuel. His first attempts were not very good, but later ones were as good as any that had been otherwise obtained. By means of such a gas analysis, he had been able to determine the hydrogen in the fuel at about 5%, and analyses of the fuel itself showed 4%, which close agreement meant that there was a very slight loss of carbonic acid, probably due to absorption in the gasometer.

It was very essential that the fluid in the gasometer should have oil in its surface, otherwise the carbonic acid would be absorbed by the water.

Respecting forced draught, the author said that "in a boiler plant of 2,000 HP, there may be 1,500HP developed at the engine, and 500HP carried up the chimney." He then assumed that if that 500HP could be saved, the whole of it would go to the engine; that, however, was not the case, the 1,500HP in the engine represents about 10 or 11 per cent. of the heat in the fuel; the heat saving had therefore to be reduced to about one-tenth, or more correctly about one-eighth, which meant as the author only intended to save 25% of the 500HP, that by substituting a fan for the chimney that there would be a gain of 17 HP.

Later on the author mentioned that the power for the fan would be about 15 HP, so that by replacing a chimney by a fan, there would be a gain of 2 HP in 1,500 HP. It was not worth taking much trouble about this for its own sake, but, of course, if the chimney was too small, or if a stronger draught was required, and for many other reasons, forced draught might be an advantage; but he would not like the Members of the Association to think there was much economic advantage in substituting a fan for a chimney. It might turn out to be an economical advantage if the draught was so sluggish that one could not get perfect combustion; then, of course, an increased draught would also increase the efficiency. But when there was good combustion there was also good efficiency, and in such a case to substitute a fan for a chimney would not be any advantage.

He (Mr. Stromeyer) was not opposed to fans in any way, but did not think they would save much of the waste heat. For instance, Howden's forced draught was started with the idea, that the heat lost up the chimney might be saved by air heaters, but the air heaters absorbed so much power that the draught had to be produced by a fan. Every marine engineer knew that he would not get a gain in efficiency by using Howden's forced draught, but his boilers would do more work, and perhaps 50% more could be got out of them than by the use of natural draught, which was an important matter for steamship owners, as more cargo could then be carried.

The perfect combustion which the author stated could be got by the use of forced draught, was not quite the advantage pointed out. For instance, if the quantity of air admitted to the furnace could be reduced by one-half without leading to incomplete combustion, the flame temperature would go up from

about 2,600° Fah. to about 5,000° Fah., but the effect of that high temperature would be that there would be overheating. He had experience with several cases where there was not the least doubt but that the very high efficiency got out of the boilers was due to the very perfect combustion which led to overheating of the plates; that trouble, he thought, chiefly occured with water tube boilers with brick combustion chambers, thick fires, and everything which goes to make a very intense and perfect flame, and if that impinges on water tubes mischief results. In some such cases of trouble, he had known people trying to find traces of oil in the boiler, but there was no oil, only a black skin on the tubes; and in his opinion many of the troubles were due to the excessive heat, which may perhaps be produced only locally. He would, therefore, like to warn the members against being too economical, as they might have to pay for it in boiler repairs.

Mr. SAM. BOSWELL thought he would be a bold man who would lay down a 2,000 HP plant and forget to put up a chimney; still there was one place with which he was acquainted where 10,000 HP was being got out of a number of boilers, and there was no chimney, but it was never originally intended so, and there was a special reason for the omission. Another case he remembered was where some people asked his firm what they could do to keep their works going whilst pulling down the stack and during the building of a new one. His firm's recommendation was to try a fan, which they did, and a chimney had never been put up again.

He thought the author rather bold in stating that "a chimney in itself has no power of suction." A fan also had no power of suction, the heat in the chimney was simply

part and parcel of the chimney, as the motor was to the fan that drove it; either of them could not be got for nothing, the heat drives the chimney and does the work in the chimney, and some kind of power must be got to drive the fan.

By using mechanical draught the author stated that 80 to 140lbs. of coal could be burnt per square foot of grate per hour. That seemed very excessive, but he (Mr. Boswell) assumed it was in a locomotive, and that the author had lost sight of the fact that in a locomotive with very thick fires, about 2ft. to 3ft. thick, and with the blast on, the fire was continually in motion; but a 3ft. fire could not be got with a stationary grate. Nearly every engineer, locomotive engineers particularly, knows the amount that can be got out of a locomotive when it is travelling, but if he comes to work it as a stationary boiler the evaporation obtained is only about one-half of that obtained when running, due to the fact that when running the fire is in such a condition that there is a better mixing of the gases, and thus a better result all round. The author stated that working the fire thick reduces the volume of air. He (Mr. Boswell) did not think this was so, but it gave a better mixing of the gases. He scarcely knew what Professor Rankine meant by "the air required for dilution," unless it was the air required, as Mr. Stromeyer had already said, for passing over the grates. To his (Mr. Boswell's) mind, air for dilution was air let behind the bridge in excess, simply to dilute the smoke; smoke nuisance could always be cured if plenty of air was sent through.

The second firing of the carbon gases was also mentioned. Whenever that took place it did not last very long. He was acquainted with a case where they had been accustomed to having the chimney on fire; an induced draught apparatus

was recommended and everything arranged for it to be put in, but before that was done the difficulty suddenly ceased.

All through the paper the author seemed to leave out altogether the question of the chimney, and did not say that he was talking of chimneys that were inefficient. All that was mentioned was that the inlet power of a fan was 1in. water column. That could always be got with a properly proportioned chimney, and with as good results as with any induced draught; so far as economy was concerned more coal could be burnt per square foot of grate, but when burning over 30lbs. of coal per square foot of grate economy was then left behind.

If more power was required out of a range of boilers without putting an extra boiler down, and they were prepared to sacrifice economy, it could be got by putting in induced draught, and burning coal at a higher rate of combustion on the grates.

The reference to small iron stacks did not accord with low temperature gases. As coal could not be obtained without sulphur, an iron stack would not last very long.

He thought the author claimed too much in stating that he could get mechanical draught at a cost of 1% boiler power; under good conditions the cost would be 3 to 4% of the power given out by the boilers.

He agreed with the author's reference to steam jets under the furnaces; there were only one or two conditions under which their application was justified, and when they were resorted to things must be in a bad way. He did not believe any good came from the undergrate blowers for helping over a difficulty; they only found boilermakers some work, because they simply convert the furnace into a sort of huge Bunsen burner, and the other parts of the boiler were "starved" for something to do.

The paper stated that induced draught increased the steaming capacity of the boilers. But, when the steaming capacity was increased beyond the economic limit, it was being done at the cost of coal. If 9lbs. of water per pound of coal were evaporated when burning 30lbs. of coal per square foot of grate, the evaporation would not be more than $8\frac{1}{2}$lbs. when burning 40lbs., therefore more was being got out of the boiler, but at a large cost of economy.

He was of opinion that the most economical conditions were 1in. water column draught in chimney, which would allow of 30lbs. of coal per foot of grate to be consumed. This could always be got in a properly proportioned chimney with natural draught, but where the chimney was not of proper size or proportions, then the induced draught was undoubtedly the proper system to adopt, and he thought Mr. Crawford might have claimed much more than he had in that direction. The speaker's rules for chimneys were as follows :—

E = area of chimney at smallest part. H = height in feet. g = grate area. For *one* boiler $\frac{1{\cdot}5\,g}{\sqrt{H}}$ = E. Two or three boilers, $\frac{g}{\sqrt{H}}$ = E. Group of four or more boilers, $\frac{0{\cdot}75\,g}{\sqrt{H}}$ = E. A good proportioned chimney is about 30 diameters (*smallest internal diameter*) high.

Mr. J. Watson said that whilst they were indebted to Mr. Crawford for bringing the subject before them, he had to confess to a feeling of considerable disappointment with the paper. For example, the actual draught in the furnaces of a boiler was not to be measured merely by the pressure in the ashpit due to a closed stoke-hold, or by the suction in the chimney, or the induced draught caused by the fan ; these might be largely nullified by obstructions or by defective

arrangement of flues. The actual draught in the furnace was the difference between the pressure of the air in the ashpit under the grate, and that over the bridge.

It was known from experience that this difference required to be not less than $\frac{1}{2}$in. on the water gauge to produce what might be called a good draught in the furnaces of Lancashire boilers, and to obtain this with the flues arranged in the ordinary way and containing an economiser, it was necessary to have $1\frac{1}{2}$in. at the bottom of the chimney. In other words, the chimney must be 200ft. high, with its internal temperature 350° above that of the external air.

The paper gave no information about the actual pressure or suction which a fan produced when used for induced draught, and it was matter for regret that they were left in the dark as to the actual difference between the intensity of a chimney draught, and that caused by a fan. Only once was this alluded to, when it was stated to be 1in. on the water gauge, but whether this meant 1in. at the fan, or in the main flue, or over the bridge, had not been made clear.

To his mind, one reason why forced or induced draught had come so much to the front, was the fact that a large proportion of our steam installations were vitiated for want of proper chimneys. If a census could be obtained, he believed that the number of chimneys with a greater height than 200ft. would be found to form a very small percentage of the total number in the country.

The author had referred to a consumption of 25lbs. per square foot of grate per hour being obtained with a chimney 300ft. high, but it could be shown that 30lbs. per square foot could be burned with a chimney much less in height. He instanced a battery of boilers working in connection with a chimney only 80ft. high from the level of the grates to the top,

in the furnaces of which it was difficult to burn more than 18lbs. per square foot per hour, whereas were the chimney 200ft. high or over, as it ought to be, the draught would be such that 25 to 30lbs. could with ease be burned, and the efficiency of the boilers and furnaces would thereby be increased.

He would have liked if Mr. Crawford had told them what he meant by a "good draught," and a "bad draught," for although he had used these expressions, he had left them in the dark as to their meaning. It appeared to him that definite information of this kind was somewhat difficult to obtain; they often saw it stated that the pressure in the stoke-hold was so and so, at some test, but this by itself was altogether insufficient for purposes of comparision, and the difference in the pressure, as he had already mentioned, ought in all cases to be given.

In the installation to which he had referred, he had no doubt whatever that a fan would be of great assistance, but a chimney 250ft. high, and 8 or 9ft. diameter, which would serve for eight or ten boilers, could be built for about £2,000, and he would like to know how this would compare with the cost of a fan installation, and a short chimney, including interest on capital, depreciation and working expenses. He doubted whether the difference would be in favour of the fan.

Mr. DANIEL ADAMSON said the general trend of the discussion that night showed the value of the matter treated in the middle portion of the paper. Most of the difficulties experienced by the speakers with forced draught would have been avoided if more attention had been given to gas analysis, as recommended by the author.

He would be glad if the author would give them some hints to guide them in carrying out this gas analysis systematically

in works; for example, he understood that the collecting pipe mentioned for conveying the gases from the flues to the apparatus would give trouble through corrosion if made of iron, so perhaps the author would tell them what to use for this purpose. Also, the author might tell them how to carry out such tests without interfering with the ordinary routine of the works, and without the attendance of a highly trained chemist.

Mr. ALFRED SAXON said that civil and consulting engineers and architects were really the people to whom the paper appealed, as they were the ones responsible for the design of the power plant of a works; an engineer was simply asked the best type of engine he could supply, and the boiler-maker asked for a certain size of boiler.

While the induced draught fan had a sphere of operation, he quite agreed with Mr. Stromeyer's remarks that those particular cases where it was applicable had to be detected, and it could not be universally applied and economy expected from it. Throughout the paper there were instances of the uncertainty of the results arising from its application, and the author had mentioned, quoting Mr. Alfred Blechyden's remarks, that in particular cases any or all of these advantages might be a source of economy, thus throwing a doubt upon the matter. Later the author mentions that a mechanical draught fan was the best appliance, and laid down the statement about 500 HP. being absorbed by the chimney, and then went on to claim certain savings; he then mentioned, thus proving the uncertainty of the claim that it cost 500 HP. to produce a draught for 1,500 HP., and that there would be an economy of 125 HP., and of the 375 HP. still going to waste another 125 HP. might be saved by using economisers, etc. It would have been better if the author had calculated what

saving would be effected in a 1,500 HP. engine working at 2lbs. of coal per IHP. per hour; and if a substantial saving was shown to be obtained in an average case he thought there would be no hindrance to the adoption of an induced draught fan more generally. An engine of 1,500 HP. burning 2lbs. of coal would use 75 tons a week; 16% on that as given by the author would be 12 tons saving in coal per week. With installations where the existing position was satisfactory, such saving could not be expected, but in the case of badly constructed flues, and small chimneys, he believed the induced draught fan had a field before it. He thought that persons advocating the adoption of boiler appliances, usually over-rated the appliances, and disappointed the users.

Mr. WILLIAM INGHAM said that whatever might be their different opinions on forced draught and induced draught, they were obliged to Mr. Crawford for giving such a great amount of useful information. It showed him (Mr. Ingham) that they had reached a very important stage. He had divided the question into three parts: first, they probably knew that about 20 years ago it was said that the principal qualification for a stoker was a "strong arm and a thick head;" they then got to the second stage, that hand firing was equal to anything which could be done in the way of mechanical appliances; they had now got to a further stage with the present paper.

He agreed with Mr. Saxon that sufficient importance had not been paid to the latter portion of the paper; everything was now being analysed. Engineers had been too much occupied in trying to get economy from the steam engine only, and had neglected the boiler, but now they were in danger of doctoring the boiler too much.

There were certain defects in connection with forced draught to which Mr. Crawford had not referred at all;

He (Mr. Ingham) happened to be interested in two cases at the present time, where with 1½in. draught at the base of the chimney they are getting black smoke. A very important phase of this question was that communities and corporate bodies generally were waking up to the fact that the smoke fiend can be killed, and are instituting prosecutions all over the country. The author had pointed out one direction in which those difficulties can be avoided, but had not referred to one of the unpleasant consequences of forced draught. In one case with which he was now dealing, they have a forced draught, and have only $\frac{3}{10}$in. draught at the base of the chimney, and yet are being prosecuted for throwing grits out of the chimney. In another case where they have 1½in. draught at the chimney base, they are being prosecuted for black smoke. Those were matters to be looked at from a practical point of view; if a great amount of coal was being used in a big plant, and an engine maker was called in, he would recommend that the engines be looked at. To illustrate this, he mentioned, that many years ago two firms in the Oldham district were discussing their relative economies. One firm was getting beautiful diagrams from the engines, and could not improve them, and were using a fairly low rate of coal per IHP. which at that time was the measure of economy, they did not take the boiler into account. In the adjoining mill, they were getting the same amount of work out of the plant at a very much less cost in fuel. The engineer at the place with the higher coal bill was called in by the directors and asked how it was that the coal bill was so much higher than their neighbours who were turning out the same weight of yarn, of the same counts. The engineer referred them to his beautiful diagrams; but, the real reason was that at the latter place they were burning very cheap fuel with forced draught; they

were burning more coal, but as the author pointed out, it was obtained at such a price that although they evaporated less water per pound of coal consumed the economy was much greater.

He would like to hear what had been the author's experience in the discharge of grits from chimneys. It seemed a point for consideration as to whether forced or induced draught was most likely to create such a nuisance. With reference to the use of a blast with a bad draught, it did not seem to him possible with $\frac{3}{16}$in. draught at the chimney base to throw out grits; even with a powerful blast it required a very good draught in the chimney itself.

Mr. J. Vose said in reference to the percentage of steam required for the steam jets, that many cases were being done at 2 to 4% of the steam supplied by the boilers. He had recollections of making the first steam jet blower, in the modern sense, in which the steam jet was part and parcel of a self-contained apparatus instead of a separate one as was formerly the case. Of course steam jet blowers were as old as boilers. The advantage of a steam jet blower was simplicity as compared with the employment of an ordinary fan. The principal cause of the present style of steam jet blower being adopted, which was to replace a fan, was owing to gas and chemical works being shown by a French engineer that they were wasting a valuable source of heat which could be utilised. The fan showed various inherent weaknesses very often at critical moments, and the steam jet by its simplicity and advantages quickly overhauled it.

The reference to fuel analysis was very interesting, as it showed the different methods of the Continentals and the Britisher. The Continentals were naturally given to that

sort of thing, and though in the past the efficiency of their boilers had not been good, the knowledge given by the use of flue gases testing apparatus was enabling them to overhaul us.

In regard to forced draught, in one of the leading works recently built, one of the principal makers of induced or mechanical draught had been given a free hand at their own request; but at the present time the apparatus was not being used because no advantage could be demonstrated at all.

Many of the troubles with boiler installations were, he thought, often due to present day boilers having to work with badly designed flues built many years ago; there were thus good reasons for using forced draught apparatus.

Respecting the issuing of grits from chimneys, he knew of a firm of paper makers who had to have the stokers taken out at their mill as the grits discoloured the water, which first went into reservoirs before being used for manufacturing purposes. Subsequently, however, the application of another type of stoker cured the trouble.

Mr. HENRY WEBB mentioned that in his opinion the difficulties experienced with boilers were often not due to the mechanical portions of the plant, but were the fault of the stoker.

Mr. W. MORTIMORE said he thought the chimney which was stated as being 300ft. high and burning but 25lbs. of coal per square foot of grate per hour must be a very poor one, or the duty an imaginary one only. He knew of a chimney 200ft. high with which they could consume 40lbs. per square foot of grate if desired.

With regard to Prof. Rankin's remark that less air was required for dilution with mechanical draught, he wished to

know whether that did not refer to forced draught, and not to induced draught. If so, some of the calculations contained in the paper would require modification.

The steam used by the steam-jet forced draught was given as 12%; but in recent tests taken by one of the leading Boiler Insurance Companies at Haydock Colliery, the amount of steam used measured from an independent boiler, was found to be 2·92 and 2·2 % only. Was the 12% obtained from actual practice, or merely supposition?

He had an actual result given him a few days ago of an induced draught installation where the steam used was stated to be 4·25% of the total power generated.

With induced draught, would the author state what was the life of the firebars?

He would have liked to have seen results given from actual practice.

The PRESIDENT (Mr. W. Henry Hunter) said he wished to suggest that something further should be considered in this country than absolute economy or even superlative efficiency. He had recently heard Professor Boyd Dawkins describing to an audience at the Society of Arts, the efforts which had been successfully made in proving coal in the South-East of England, mainly in Kent, which had been described as "the garden of England." Many people, and one could not help but sympathise with them, were up in arms at Kent being made into a colliery district. But was there not contained in Mr. Crawford's paper a method of remedying what was undoubtedly a great blot upon modern civilisation, the destructive effect of all that was charming and beautiful in nature by means of manufacturing and other industrial operations; the very embodiment of that destructive effect was

seen in works' chimneys. He had himself built many chimneys, but never without pangs of conscience and inward pains. Mr. Watson had talked with the greatest readiness of chimneys 250ft. high. The top of such a chimney would be visible 14 miles away, and thus over an area of 200 square miles that chimney would be an object of abhorrence to everyone living in that area.

Mr. ROBERT MATTHEWS in proposing a vote of thanks to the author, said he had expected that Mr. Ingham would have made some mention respecting the waste gases. Which was the lesser of the two evils: to have induced draught, with a low chimney, or to have a high chimney, and get the waste gases diluted with air. Personally he would prefer the latter, and the resulting much healthier atmosphere, than a number of short chimneys as were used in iron works.

Mr. GEORGE SAXON in seconding the vote of thanks, said that although the paper was open to much criticism, the information given was very valuable.

Mr. CRAWFORD subsequently sent the following reply: the paper, as read, had no intention of going so minutely into details of the subject as some of your criticism would imply, but is primarily meant as information for the general user of steam boilers.

The paper refers to the total quantity of air necessary for complete combustion, but does not suggest as to how this air may be applied to the furnace, whether through the fire bars or through the furnace door. As a matter of fact, whether the air for combustion passes through the fire bars, and a portion through the furnace door, depends on the area and arrangement of the air space through the furnace bars, that is, whether the bars are arranged with uniform air space throughout, or with a greater air space at the front of the furnace. The latter is the

best arrangement, and preferable to admission of cold air through the furnace door. This conclusion is arrived at by the analysis of the gases leaving the boiler, and the reduction of smoke under working conditions. The result may differ from scientific views, but at any rate is found to be correct in practice.

Mr. Stromeyer's remarks on the analysis of flue gases are quite correct for absolute accuracy, but such care is altogether unnecessary in ordinary boiler work where the percentage of CO_2 averages about 6 % instead of 13 % or 14 %.

The "Orsat" apparatus I merely mentioned as an occasional instrument for testing flue gases, but for a continuous analysis and a record of same, without rubber pipes or tubes, I described the "Simmance-Abady Combustion Recorder" (made by Messrs. Alex. Wright & Co., Ltd., of London), which Mr. Stromeyer does not mention. This Instrument gives a daily record of the percentage of CO_2 and its variation; also on the same chart is recorded the strength and variation of the draught. With this instrument no rubber tubing is used, and the results obtained are practically accurate, and show minutely every variation in the working of the fires.

In reference to Mr. Stromeyer's remarks on induced draught, 1,500 HP is developed by the engine and 500 HP is absorbed by the chimney in producing the draught. This is clearly shown by the temperature of the chimney being equal to quarter of the furnace, therefore the losses in the engine and chimney are on the same basis. If 1,500 HP in the engine represents 10 or 11 % of the heat in the fuel, the 500 HP in the chimney also equals 10 % or 11 % of the total heat in the escaping gases, and this heat may be transferred to more useful and economical purposes. As a matter of fact, 1 % to 1½ % will drive a fan, while a chimney requires 20 % to 25 % for the same purpose. In the majority of works a chimney should be used to remove gases, but not for the purpose of producing draught.

Mr. Stromeyer says "he would not like the members of the Association to think there was much economical advantage in substituting a fan for a chimney." I have installed over 700 induced draught fans in Lancashire alone, and many of them take the place, so far as draught is concerned, of the most lofty and well designed chimney that could possibly be erected. In my paper it is clearly shown that a chimney is absolutely useless without heat, and why 20% to 25% of the total heat should be passed through it to produce a draught that can be got by 1½% in a fan is beyond my conception, and is an absolute waste.

In reply to Mr. Boswell I would say that "the air required for dilution" meant extra air supply, so that the air might come in contact with every particle of coal undergoing combustion, yet the air required for dilution in such a case meant waste, and would be shown by the analysis of the gases. With a thick fire less air would pass through with the same draught, a better mixture would be produced, and on analysis a higher percentage of CO_2 obtained.

Mr. Boswell mentions that I leave out altogethor the question of the chimney. As a matter of fact, I look on a chimney as a means for conveying the waste gases clear of the works, and for no other purpose. An induced draught fan may work at 1, 2 or 3 inch water column, or whatever water column may be necessary for the coal in use, whereas with chimney draught, coal must be selected to suit the draught produced by the chimney. For induced draught fans I have mentioned the maximum horse-power required by a properly proportioned fan for the maximum duty as being from 1 to 1½%, and when these figures are exceeded the conditions must be peculiar. I have never seen a fan requiring 3 to 4% of the power given out by the boilers, nor would I advise any purchaser to have one. The economic limit of a boiler is fixed by the economiser pipes, or

other heat absorbing appliance, and should not be exceeded as anticipated.

I regret that Mr. Watson did not find all the information in my paper that he desired. However, I will endeavour to make up whatever has been deficient.

For good average working and proper combustion of the coal I consider ¾in. water gauge necessary at the boiler damper. With this water gauge the bars must be properly covered with coal and a thick fire maintained, otherwise the percentage of CO_2 will be low, due to excessive air passing through the furnace. To obtain ¾in. water gauge at the boiler damper may necessitate 1½in. or 2in. at the fan inlet to overcome resistance in dampers, economisers and flues. As already shown, such a high water gauge could not be produced by a chimney without an immense waste of heat. The fan will produce the water gauge suction necessary to overcome resistance in the flues and maintain the desired water gauge over the fire. In a number of installations recently installed the water gauge is 3in., and is not too much for the duty required. Each fan is driven with a 280 HP motor with economical results. For this duty a chimney would be absolutely useless. The 1in. water gauge referred to in the paper applies at the boiler damper, and which I consider is a fairly good draught for a Lancashire boiler, although a great deal more may be taken out of the boiler without loss with suitable economisers. Mr. Watson is quite right in saying that a greater amount of coal than 30lbs. per square foot of grate bar could be burnt with a chimney 300ft. high, but I would say, not economically, as the fires must be thick to obtain the correct percentage of CO_2. and to avoid additional waste. A chimney is entirely out of the question as a draught producer with economy.

Mr. Daniel Adamson is right in mentioning the improvements that may be effected if more attention was paid to the neglected subject of gas analysis.

The piping to the instrument for analysis of the flue gases may be of iron or glass. If of iron, and blown through once a fortnight, the pipe keeps perfectly free and the oxidisation has practically no effect on the readings. The proof of this has been corroborated by substituting glass tubing.

The large number of instruments installed in the immediate neighbourhood prove their simplicity and accuracy in working of the boiler plant, and only require a few minutes' attention each day.

Mr. Alfred Saxon seems to run in the same groove as Mr. Stromeyer, and quite agreed with the latter in that induced draught could not be universally applied and economy expected from it.

The language of the paper is not intended to be particularly strong in pushing the claims of induced draught fans, but merely states facts gained by experience. Mr. Saxon also refers to the 1,500 HP. engine, but this, I think, has been referred to already, and from his criticism of the paper it is evident that little interest is taken in the subject when he approves of 25% of the total heat in the coal going practically to waste in producing a draught. As a matter of fact, the induced draught fan has not only a field before it, but is in a very big field at the present moment.

Mr. William Ingham mentions a works where with 1½in. draught at the base of the chimney they are getting black smoke. I would suggest that the draught is taken in the side flue or at the damper before leaving the boiler, as a chimney draught is often destroyed by dampers and contracted flues before reaching the boiler furnace.

In the case of $\frac{3}{16}$in. draught at the base of the chimney, and grits being thrown from it, I would suggest working with thicker fires and getting a better analysis of the gases by reducing the volume of air passed through due to the fires being too thin. The

fact of grits being thrown from a chimney is due to thin fires and an excess volume of air in proportion to combustion, and on analysis of the gases a low percentage of CO_2 would be shown.

Mr. Vose mentions steam jets requiring 2 to 4% of the steam supplied by the boilers.

My experience of steam jets shows 8 to 10%, and even 12% of the boiler capacity, and can in no way compare favourably with an induced draught fan. These fans are now made substantial, and equal in running capacity to any other part of the machinery, and when coupled with a CO_2 recorder, a report is produced that cannot be surpassed by any other appliance. The CO_2 recorder referred to is made in London, and entirely English.

I quite agree with Mr. Mortimore in his having seen a chimney 200ft. high burning 40lbs. of coal per square foot of grate, but I do not think with economy, and would say that in analysis 5% or 6% of CO_2 would be the maximum owing to thin fires.

It is immaterial whether Professor Rankin used forced or induced draught, the conditions for analysis are the same.

The 12% steam used for producing draught by jets was tested in a battery of boilers where one boiler, at its full capacity, was in use to supply the jets only on the remaining seven.

With induced draught the life of the fire bars in all cases is increased.

THE THIRD FUNCTION OF ELECTRIC TRACTION MOTORS.

READ SATURDAY, 24TH NOVEMBER, 1906,

BY

MR. EDWARD H. JOHNSON,

(LONDON.)

Although ohms, volts, and amperes; direct and alternating currents; single phase, tri-phase, and multi-phase; high and low frequencies; and all the rich and varied nomenclature of the electric art have made surprising progress towards the status of household words, I venture to think that few of us have yet acquired such familiarity with the apparatus to which these terms apply as to need no coaching when a new development of the art is to be discussed. I shall, therefore, without further apology, preface my paper with a few remarks descriptive of the composition and characteristics of the methods and apparatus which forms its subject matter.

The subject to which I have the honour of inviting your attention and subsequent discussion was named by me to your Secretary, practically as given in your programme; but I have since thought it could be more aptly designated as "The Third Function of Electric Traction Motors." It is, in fact, the specific purpose of this paper to dwell upon the evolution of this newly-fledged attribute of the electric motor—I use the term advisedly—for, although the attribute *per se* is *not* new, it is nevertheless but just now emerging from the chrysalis stage into the sphere of developed things.

It is, of course, common knowledge that a dynamo electric machine is possessed of two functions; that it is capable of absorbing electrical energy from an external source, and through its motor function, converting it into mechanical power, and that it can reverse this operation by absorbing mechanical power, and through its generating function convert that into electrical energy; but what is not so well known is that electrical energy may thus be regenerated from a moving car or train and delivered to the trolly, the third rail or the other supply conductors, thence to pass on and assist the prime supply in creating mechanical power elsewhere.

It is this economic attribute of "passing on" the recovered energy to useful employment outside the car or train developing it that constitutes the newly-developed third function. Hitherto, except in a small way and in connection with accumulators, the regenerated product of the braking function has been wasted in the useless heating of special resistances, or in energizing other braking factors, thus limiting its office to that of braking, *i.e.*, one and the same function. The third function, though inherently present, was in such use practically non-existent. It was, so to speak, in a dormant stage,

In order that the difficulties, which had to be overcome in evolving this function from the state in which it had been so long left, may be appreciated, I will give some explanation of the composition and characteristics of the types of motors and methods of motor control which have been adopted, or are recognised as adaptable to direct current traction work.

MOTOR TYPES.

There are two simple, and one composite, types of direct current traction motors (with which alone we are concerned at present). These are termed respectively the "series," the "shunt," and the "compound."

The magnetization essential to each of these types is developed by utilising therefor a small percentage of the input to the motor. The divergence of type and consequent difference of characteristics, arises from the differing methods employed in applying the electric current to the magnetizing coils, as will appear from the several descriptions which follow:

THE SERIES TYPE.

In the series motor the magnetizing coils consists of a few turns of heavy wire offering but little resistance, and therefore having great current carrying capacity. These coils are placed in the main circuit with the working armature, and are in consequence traversed by the entire operating current which, passing through them and the armature *in sequence*, gives to the motor the designation "*Series*." The entire operating current thus being active in creating the magnetic field, and the quantitative value of this current being, as it is, dependent upon the work done by the motors, it is apparent that in this type of motor we will have a magnetization, and consequently a motor speed, dependent upon the work the motor is called upon to do; that is to say, the speed will automatically vary with the load, increasing under a light, and decreasing under a heavy load, and this, to the full value of the conditions prevailing whatever they may be; it will, for instance, continue its accelerating function even though the driven vehicle be actually running away. In other words we have in this type of electric motor the usual mechanical motive power characteristics.

THE SHUNT TYPE.

In the shunt motor the magnetizing coils consists of many turns of fine wire aggregating a considerable resistance and therefore having but small current carrying capacity. These coils are connected in shunt relation to the armatures hence the current traversing them is independent of the operating current

and is moreover fixed in value by the resistance of the field coils themselves.

Such a motor having a more or less constant magnetization will have no speed flexibility; it will, in fact, have a speed constant under all conditions of load, and will, in consequence "fight" to maintain this constant when subjected to variations of load potential, as in ascending or descending a hill, and as in accelerating or retarding momentum. The shunt motor is thus seen to possess animal rather than mechanical characteristics, it objects alike to being restrained or hurried by external conditions. In this objection to being pushed we of course have the shunt motors second function, viz.: that of holding back, *i.e.*, a power brake.

THE COMPOUND TYPE.

The compound motor is fitted with both kinds of magnetizing coils, and is in consequence given a field excitation having something of the characteristics of both the series and the shunt motors. The shunt excitation is present for the purpose of giving the generating function and the series excitation for purposes of speed variation.

When one and the same machine is used for both motoring and generating, and the compounding is associated with each function, the two methods of exciting will co-operate in one of the functions, thus strengthening the field, but in the other they will be in opposition, thus weakening the field. If, for instance, we pre-determine their co-operation to be in the motor function we shall have a motor field strength which will be augmented in proportion to the series excitation employed, and will have a generating field strength weakened in like proportion. Manifestly we thus have, in compounding, a means for determining the characteristics of the motor and therefore a means of regulating its speed notwithstanding the presence in the motor of the inflexible shunt characteristic.

Moreover, it must be borne in mind that since the series excitation varies with the operating current, and therefore with the load, we have in the compound machine an automatic adjustment of the ratios of the compounding to the requirements of the work, to all intents and purposes the same as in a series motor *per se*.

METHODS OF CONTROL.

There are but two generic principles of varying the speed of an electric motor. These are: (1) to vary the electro motive force of the current utilised by the armature; (2) to vary the strength of the magnetic field in which the armature works. The electrical engineer has been chiefly occupied with devising efficient and effective means for practically applying these principles. Obviously we cannot vary the electro motive force of a current supply, common to two or more units of differing requirements, hence we are compelled to provide each unit with its own independent means of electro motive force control. This is done for the armature circuit by establishing therein a high initial resistance at the starting moment and gradually reducing it, as the motor gains way, until the full electro motive force is effectually applied to the armature.

There are two methods of obtaining and varying this armature circuit resistance, one of which wastes the energy it absorbs, and one of which usefully converts it. The first consists of coils of wire, or iron grids, whose sole function is to waste in heat what the motors cannot safely receive. The second consists in the sub-division of the motive power into two or more motor units and placing these in series with each other. Manifestly the energy expended on the latter is efficiently utilised in developing the motor function. In the case of the non-active resistance a fine speed graduation is obtained through the employment of a considerable initial quantity of this resistance, and its gradual reduction by small steps. In

the case of the active resistance method two motors are usually employed, in conjunction with some non-active resistance. These motors are initially connected in series with each other, and with the non-active resistance; and as the resistance is cut out, producing a rise in speed, they are thrown into parallel, thus initially dividing the electro motive force between the two motors and the non-active resistance, but finally applying it in full to each individual motor.

It will be observed from the foregoing that neither of these means of varying the electro motive force at the armature terminals is ideal in theory or in practice, nor do they realise in practice the inherent economy of the electric motor, nor its amenability to control. The non-active resistance, though potential of fine speed graduation, involves waste. The active resistance though avoiding waste involves abrupt and more or less violent speed changes. These changes are in fact precisely analogous to the changes effected through positive gear in mechanics; fortunately, however, the electric art, unlike its less fortunate mechanical sister, has found the "missing link" which was needed to smooth out its too abrupt changes, and series paralleling is thereby made feasible and superior to spur gear changes.

This method of speed control is, in fact, our second generic principle, and is usually designated as—

MAGNETIC VARIATION.

This principle of control is ideal both as regards efficiency and speed graduation, yet *it* also has its limitation; it is, in fact, fundamentally limited in effective range. For this reason, it has failed, and must ever fail as a *prime* source of speed change in traction motors. It has, in consequence, been relegated to the duty of smoothing down the abruptness of the wider speed changes effected through the several other means employed.

We may, of course, effect a wide range of speed change through field variation alone, but we can only do so by a prohibitive increase of motor dimensions. The capacity of a motor being determined by the field strength obtainable from its magnetic body, *i.e.*, the motor frame, it is obvious that we cannot weaken this field strength to produce speed change, or for any other purpose, except we sacrifice torque—and "it's torque that does it" in traction work. In other words, field strength, being the determining factor of motor dimensions, may not be given a wide variable except through dimensions otherwise quite uncalled for. This fact takes field regulation out of the category of prime factors in the control of the speed of traction motors, for the reason that the *available* space for such motors is very limited, whereas the demand is for an ever-increasing motor capacity. Thus compactness becomes a controlling factor, and renders *bulk* as transparently impracticable as it is unscientific. Nevertheless, and notwithstanding its shortcomings as a prime factor, field variation is so essential as a subordinate factor of speed control that it is quite within bounds to say that deprived of its aid electrical traction would not exist to-day. We may, therefore, usefully inquire as to the ways and means of its production and manipulation.

The means employed for effecting a variation of the electromotive force applied to the field coils and, therefore, of varying field strength, are identical with those employed for varying the electro motive force at the armature terminals, viz.—the series-paralleling of the energizing coils and the use of auxiliary waste resistances; in this case, however, the waste is small, since we are dealing with small prime quantities; hence the use of these waste resistances is in this connection both economical and practicable.

We thus find that there has come to be employed three quite distinct means of adjusting the constant electro motive force of

the prime supply to the varying requirements of the individual equipment. We find, moreover, that while each of these means has its own limitation they one and all possess a contributive property of more or less value. Theoretically, the sub-division of the motor units, that is to say, the series paralleling of the armature circuits offers the most satisfactory solution of the problem of control, but practical considerations as regards mechanical complications intervene and compel a limit to such sub-division. In the non-regenerative system the happy medium of this sub-division has been found to be in a single multiple, *i.e.*, 2 motor units. In the regenerative system, for reasons which will appear later, this medium is found in two couples, *i.e.*, 4 motor units. It is the purpose of this paper to show how the best qualities of these several means have been utilised to the greatest advantage in overcoming the obstacles to the commercial application of the regenerative principle; which obstacles were erstwhile held to be insurmountable.

The standard tramcar equipmentwhich has been evolved, and from which the data herewith submitted has been obtained, is composed of the following:—The usual two motor couple, motor suspension, spur gears, platform controllers, trolley collectors, cut-out switches, etc., etc., to which is added: One special controller or field changer, one special excess voltage switch, and a mechanical power brake.

The nature of the differentiations from the non-regenerative equipment and of the supplemented features may be briefly summarized as follows:—

THE MOTOR FRAMES.

These are of the standard rating, type, dimensions, and construction, save only that there is an additional opening for the inspection of the extra commutator. Fig. 1, Plate I.

THE ARMATURES.

The windings of these are divided between two commutators so as to yield two independent armature circuits per motor, thus to allow of double series paralleling with but two motor units. The divided windings are so connected as to effect a balance of their electro motive force when operating in parallel.

THE FIELD WINDINGS.

The fields are of the usual four pole type, but each pole is supplied with a relatively small series, and a full shunt winding. The series turns are ample for the purpose of compounding but not sufficient to give in full value the simple series excitation, hence the shunt coils are arranged so as to be connected in parallel and made to serve as series turns when full series excitation is required.

THE FIELD CHANGER.

This is a circuit controller, made to operate automatically through the agency of an electro magnet, of solenoid form, and a retractile spring or gravity. Its function is to effect the conversion of the motor characteristic from series to compound, and *vice versa*. It is controlled by the driver through the medium of a thumb switch placed in the handle of the main, or platform controller and may be considered the key to the system. Fig. 2, Plate I.

EXCESS VOLTAGE PREVENTOR.

This is an electro magnetic switch, so placed and adjusted as to deprive the motors of their shunt excitation in case of accidental loss of trolley contact, thereby preventing the excessive rise of voltage which would ensue from the unopposed voltage development of the motors acting as generators.

THE MECHANICAL POWER BRAKE.

This consists of the following parts:—The usual wheel and track shoes with their accompanying system of leverages, a

specially constructed spiral band the purpose of which is to frictionally grip the axle—Fig. 8, Plate I.—or a shaft driven thereby, and thus exert a pull on the brake levers—Fig. 5, Plate I.—an electro magnetic solenoid carrying a weighted core, the duty of which core is to impose a drag on the free end of the spiral and thus bring the brake into action, the function of the solenoid of course being to pick it up and hold it when the brakes are not required. Contacts for controlling the solenoid are placed in both the platform and the automatic controllers, and in a special emergency switch conveniently placed at the hands of both the car driver and the conductor.

THE THIRD FUNCTION.

The phenomenally rapid growth of electric traction, resulting in its, practically universal, adoption for tramways and its hardly less general use in all short haul railway traffic, is due rather to an all round superior fitness than to any one pre-eminent quality. Being economical in operation, easily expanded, and time saving, it has created a revolution in local transit, that industry is no longer relegated to small private capital, but is now raised to the dignity of "trust" combinations with—so to speak—a seat on the world's financial exchanges.

The development of the industry has been so rapid as to occupy the electro mechanical genius with problems of speed control and stability rather than with those which relate to operating costs. In fact electric power is so inherently cheap that suggestions of further cheapening it have been pooh-poohed and the meddler making them has been systematically shown the door by that ubiquitous functionary, the office boy, as a part and parcel of his ordinary official duties, but there are signs of a dawning consciousness that dividends may be substantially increased by cheapening, even that which is already cheap. Moreover, there are other factors at work developing a realizing sense of the importance and need of a

more complete and scientific utilization of the possibilities of the electric motor.

Looked at from an economical point of view, it is of course natural, that with the enormous increase in the scale of operation there should come a realising sense of the value of small unit savings, and that serious consideration should be given to ways and means for conserving them; but there is a still more potent force at work developing a demand, albeit unwittingly, for the more complete utilization of the motor's functions. This is the voice of public opinion, which having been raised in consequence of multiplying accidents is now demanding greater care for safety in operation.

The electric vehicle has grown great in itself even as it has multiplied, while the gradients have, for obvious reasons, remained practically unchanged. The dangerous conditions thus created have not been met by a corresponding development of the braking and other safety factors, a fact now becoming apparent through frequently recurring accidents.

With the developing inquisitiveness as regards economical improvements there has thus come to be associated a kindred spirit of inquiry as to improved factors of safety. It is in response to this dual inquiry that I propose to show how the motors themselves may be made to yield proximate finality in these respects by combining in a practical and workmanlike manner all three of their inherent functions. The problem in this, as in the case of the development of the single function of propelling, is one of control, but manifestly a much more difficult one since it is necessarily complicated by the need of harmonising characteristics which are more or less inherently antagonistic.

Even with the simple series motor, which has an inherent self-regulating capacity, the problem of economical and efficient control has presented difficulties which have proven to be well-

nigh insurmountable. This fact leaves us without surprise that the more inflexible shunt type has been relegated to that limbo, which an American ex-President, Mr. Grover Cleveland, was wont to call "innocuous disuetude"; and by the same token we have no difficulty in apprehending that serious obstructions were to be encountered by those who would endeavour to combine in a system of control, the shunt characteristic of inflexibility with the flexible characteristics of the series motor, in such a manner as to secure the efficient and harmonious co-operation of the functions of propelling, retarding, and regenerating; nevertheless these difficulties have finally been surmounted in a thoroughly practical manner and the three functions have been made harmoniously operative, as I shall presently show.

THE SERIES COMPOUND REGENERATIVE SYSTEM.

In this system, in the development of which I have had the invaluable services of Mr. Robert Lundell, of New York, and Mr. Gustaf Lang, of London, the aim has been to evolve practical means for embodying only such factors as are inherently efficient and economical, both in theory and in practice.

This more scientific combination of the essential factors in traction work, though at the outset seeming comparatively easy of accomplishment, has nevertheless consumed many years of patient study and a huge expenditure of money, of course with the usual concomitants of elation and disappointment.

A fundamental aim in the present design is to relegate shunt excitation to the single duty of regenerating, in which duty alone it is indispensable, and at all other times to operate the motors under series excitation simply. In realizing this aim it has been found practicable to retain in a regenerative system the inherent advantages of the standard series traction motor, and to avoid the losses and incidental disadvantages of shunt excitation.

Manifestly this segregation of field characteristic, as between the duty of propelling and that of retarding the vehicle, demands means for instantaneously changing from series to shunt, or compound, and *vice versa* according as the duty of propelling, or that of retarding, may be demanded of the motors. It is likewise obvious that since this change of function may take place at any position of the controller, *i.e.*, at any speed, the self-adjusting or regulating characteristic of the magnetization must be present at every circuit change, whether made during acceleration or retardation; *e.g.*, it must exist as well in compound excitation as in simple series, and, moreover, must in each case be of such value as to effectively graduate the greater or less abruptness of such circuit changes.

To this end the field windings are so proportioned as to produce the right resistance and current carrying capacity to yield the practical limit of magnetization, both when the coils are connected in series across the full line voltage and when grouped in parallel and in series with the armatures. It is, at the same time, essential that there shall be no idle copper or waste field space; that is to say, the maximum attainable magnetization limit must be had with an irreducible minimum of field copper and motor dimensions, otherwise both cost and dimensions become prohibitive.

As hereinbefore stated the field windings are in the form both of series and of shunt coils; the latter are so arranged as to be convertible into series turns, and made available to help out the fixed series turns, which latter are not of themselves sufficient to effect full series excitation. The fixed series turns are required for three purposes:—

1st. to counterbalance the shunt excitation and so prevent an excessive current rush during regeneration, thus effecting a smooth retardation without being compelled to resort to an excessive sub-division of the field regulating steps. When series

turns are employed three steps in field variation have been found to be sufficient to produce the essential graduation. Moreover, if series turns are not employed and simple shunt excitation is relied upon, the current—at the moment when the magnetization happens to be in excess of that which corresponds with the speed at which the car may be actually running—would be excessive for an instant, but would quickly drop to an approximate constant, of too low a value, to be adequate to the duty required. On the other hand, when the series turns are employed, to counterbalance the shunt excitation and prevent this initial current rush, the current decrease is much less rapid and the practical working constant retains a much higher value.

2nd. Series turns are further invaluable for maintaining a certain degree of magnetization, and thus preventing the destructive effects of the magnetic discharge which would ensue from the grouping and re-grouping of the shunt field coils, as well as to prevent the sparking arising from ordinary field interruptions.

3rd. These turns also serve the purpose of preventing violent current rushes at the moment of making the series parallel circuit changes, by maintaining always a certain degree of magnetization without the aid of which the full magnetization, so essential to choke back the current rush at this moment, could not be obtained quickly enough to be effective.

The diagrams of the several armature and field circuit connections are given (Plate II.) in order to more fully denote the ratios and proportions which experience has shown to be the happy mean for each of the nine steps which constitute the range of manual control. The accelerating and retarding connections of each step are shown in juxtaposition in order the better to compare the respective requirements of acceleration and of retardation for approximate speeds. It will be observed

that the first accelerating step naturally becomes the last retarding step, and so on throughout the range.

By virtue of this sole reliance upon the active armature resistances for sub-dividing the electro motive force, (and of their sub-division into sufficiently small units to bring the necessary abrupt steps consequent upon the circuit changes within the compensating capacity of a commercially available degree of magnetization,) we have been enabled—as will appear from a study of the diagrams presented herewith—to achieve the following advantages:—

First: A substantial decrease of the motor input.

Second: Regeneration down to a very slow speed.

Third: Smooth accelerating and retarding movement.

Fourth: New and effective factors of safety.

In support of these claims I append a table of comparative tests made at Norwich and a statement of the chief engineer, Mr. Alan N. Banister, as to the quality of the operation. (See pages 332, 333.) These tests are preliminary to the more exhaustive tests which have yet to be made. They were, however, made under conditions sufficiently identical to be of substantial value. The data obtained are, therefore, sufficiently reliable for our present purposes.

In studying this question we must keep in mind the fact that no two tramways present identical conditions, hence the results here given become simply a gauge wherewith to measure the potential of the system when employed under other conditions. The factors most favourable to regeneration are those which constitute the greatest bar to high-class tramway service, hence it is in such service that the utilization of the three motor functions achieves the highest value. These factors are:—

High schedule speed through congested traffic in the streets and frequent stops and heavy grades. Norwich conditions are

neither particularly favourable nor unfavourable, and may therefore be taken as a fair mean of tramway conditions in general.

An essential concomitant of the regenerative braking function is a supplemental mechanical power brake. Regeneration, being the product of motion, necessarily ceases at some point short of final rest, hence there is needed a supplemental power brake which will accumulate a braking force and maintain it after the car has come to rest. A necessary corollary of this supplemental need is that it shall be supplied automatically, that is to say, independently of the driver; otherwise, the choice being with him, he would be apt to employ both braking factors simultaneously, in which case the regeneration would be robbed of much of its economic value; or, on the other hand, he might bring the mechanical brake into operation too late, in which case there would be a dangerous lapse of all braking effort. A device has therefore been introduced which utilizes the energy of the moving car, and applies it to the ordinary wheel and track shoes through the medium of a friction spiral surrounding the car axle, or an auxiliary shaft driven thereby; this friction device is kept normally out of action by means of an electromagnetic solenoid. This solenoid is controlled by contacts, placed in the main controller at the point where regeneration ceases; hence the driver has but to continue the controller movement through the regenerating cycle on to this mechanical braking point in order to bring his car to rest and hold it there. When the controller is again moved to start the car the solenoid is energized and releases the frictional spiral, thus leaving the car free to respond to the motor effort. Provision is also made for bringing this brake into action in conjunction with regenerative braking, so as to effect an emergency stop by uniting the braking force of the two. Further use is made of its potential characteristic by providing that it be automatically brought into action in the event of any failure of the electric

current, as, for instance, through the loss of trolley contact or other circuit disruption or the failure from any cause of the main supply current. In such event the solenoid loses its energizing force and the friction spiral becomes operative. We thus have in this device an additional safety factor and a valuable one, since its action is inevitable and instantaneous in the event of the car being deprived of its motor control.

Summing up the direct and indirect advantages of this threefold use of the traction motor, we find them to be sufficiently substantial to warrant the conclusion that not only will the system soon come into general use, but that such use will speedily become so universal as to constitute it the standard system for all traction work. Among these advantages we find the following :—

1st. Substantial energy saving varying anywhere from 20° to 50° according to the conditions existing.

2nd. A reduction in capital investment in generating plant and distributing system, practically in the direct ratio of the energy saving.

3rd. The introduction of new and valuable factors of safety, inclusive of the simplification of the motor man's duties.

4th. A material saving in the nett upkeep cost of permanent way, rolling stock, and generating plant.

As an offset to these advantages we have but a slight increase in the complications of car equipments and a slight increase in these equipment costs.

A further claim for the employment of the motors in their regenerating capacity is made by a writer in the *American Street Railway Journal.* Speaking of the new subway in New York City he states, that the metal particles set free by the wear of wheel and brake shoes amounts in quantity to "as much as the average weight of dust in the winter street of New York,"

and that the "heat deters people from using the subway." He suggests regenerating braking as the best means for reducing these ills.

The system I have now had the pleasure of describing to you may be readily adapted to train operation in connection with the multiple unit control system; likewise the supplemental mechanical braking system. It will be observed in this connection that, as in the multiple unit method of control, each car equipment, both as to its motor and its braking system, is a complete unit in itself, and may be controlled individually or in multiples with equal facility.

It may here be appropriately mentioned that the system is being tested at Blackburn upon a four-motor car, in which the standard single commutator motors are being used. The motors are, in fact, the old standard series motor, converted to our purpose by the substitution of our compound field windings for the simple series windings with which they were previously equipped. This demonstration has therefore a double value, in that it shows that existing motors may be used by employing four to the car, and that scrapping may thus be avoided; and at the same time it shows that the double commutator motor is not an absolute essential. It should, however, be pointed out that whereas the tests thus far made at Blackburn show a net saving of about 25%, more than this could undoubtedly be secured if two of the special motors were employed instead of the four standards. The losses would be less. Moreover, we have not secured the best attainable results with the four single motors, because of not having provided the special controller necessary to operate the motors in the most efficient way. Enough has, however, been shown to demonstrate conclusively that by taking four old type motors, the series compound principle may be advantageously applied without the need of constructing special motors.

In this connection, I desire to record my obligation to Mr. Cowell, Manager of the Blackburn Tramways, for courtesies extended and patient consideration shown; also to pay my respects to Chief Engineer and Manager Alan N. Banister, of the Norwich Tramways, who has greatly assisted me by the intelligent application of his practical knowledge and skill in the work of adapting the system to operating conditions.

I have also to acknowledge a deep indebtedness to Sir Clifton Robinson, of the London United Tramways, for facilities afforded me in gaining that experience without which ultimate success is impossible.

In conclusion, I desire to put on record the fact that while the system I have described is fundamentally based upon the labours of Mr. Lundell and myself, and has been brought to the present high state of commercial perfection by the indomitable perseverance and technical ability of my present associate, Mr. Lang (who is present to-night to take part in the discussion), I should not have been able to achieve the present satisfactory finality but for the advice, encouragement, and suggestions so frequently given me by my personal friend, the eminent consulting engineer, Horace F. Parshall, Esq., to whom I now gladly pay this tribute of appreciation.

APPENDIX.

Comparative Tests of Energy Consumption between the old Standard Equipment and the new Regenerative Equipment, carried out on the route Mousehold—Unthank Road Terminus in Norwich, 2nd October, 1906.—J. Gustaf V. Lang.

Section.	Distance in Miles.	Time (including Stops) Seconds.	Number of stops.	Number of stops per mile.	Total time of stops, Seconds.	Time of running period, Seconds.	Average speed during running period, miles per hour.	Wattmeter readings * R7376	Wattmeter readings * R618	K.W. hours, input.	K.W. hours, output.	K.W. hours, net.	K.W. hours per car mile.	Saving in % of Standard Car.	
Mousehold		310	5	9·2	12	298	6·55	52·59 53·30 ·71	26·69 27·37 ·68	·695		·695	1·28		Standard Car
	·544														
Cavalry Barracks		351	5	9·2	12	339	5·76	64·59 64·98 ·39	41·80 42·44 ·64	·64	·39	·25	·46	64·0	New Car.
Cavalry Barracks		327	4	4·73	7	320	9·52	53·30 54·21 ·91	27·37 28·24 ·87	·89		·89	1·05		Standard Car.
	·846														
Post Office		318	5	5·9	12	306	9·95	64·98 65·20 ·22	42·44 43·28 ·84	·84	·22	·62	·73	30·4	New Car.
Post Office		1107	13	7·2	118	989	6·59	54·21 56·76 2·55	29·24 30·89 2·65	2·60		2·60	1·41		Standard Car.
	1·805														
Unthank Road Terminus .		1081	13	7·2	55	976	6·66	65·20 65·50 ·30	43·28 45·78 2·50	2·50	·30	2·20	1·19	15·30	New Car.
Unthank Road Terminus .		1262	11	6·09	191	1071	6·06	55·76 58·79 2·03	30·89 32·89 2·00	2·015		2·015	1·09		Standard Car.
	1 805														
Post Office		1228	11	6·09	212	1016	6·4	65·50 66·10 ·60	45·78 47·51 1·73	1·73	·60	1·13	·63	44·0	New Car.
Post Office		497	8	3·54	154	343	8·89	58·79 59·49 ·70	32·89 33·59 ·70	·70		·70	·83		Standard Car.
	·846														
Cavalry Barracks		443	8	3·54	126	317	9·61	66·10 66·26 ·16	47·51 48·21 ·70	·70	·16	·54	·64	22·82	New Car.
Cavalry Barracks		293	8	5·52	4	289	6·76	59·49 60·99 1·50	33·59 35·10 1·51	1·505		1·505	2·77		Standard Car
	·544														
Mousehold ..		314	8	5·52	6	308	6·34	66·26 66·40 ·14	48·21 49·60 1·39	1·39	·14	1·25	2·3	16·91	New Car.
Mousehold .. .		608	8	7·36	16	587	6·67	2·21	2·19	2·20		2·20	2·02		Standard.
Cavalry Barracks	1·088														
Mousehold		665	8	7·36	18	647	6·05	·53	2·03	2·03	·53	1·5	1·38	31·8	New.
Cavalry Barracks		824	7	4·13	161	663	9·19	1·61	1·57	1·59		1·59	·94		Standard.
Post Office ..	1·692														
Cavalry Barracks		761	8	4·73	138	623	9·78	·38	1·54	1·54	·38	1·16	·69	27·0	New.
Post Office . ..		2369	24	6·65	309	2060	6·31	4·58	4·65	4·615		4·615	1·28		Standard.
Unthank Road .	3·610														
Post Office . ..		2259	24	6·65	267	1992	6·52	·90	4·23	4·23	·90	3·33	·92	27·9	New.
Mousehold ..		3796	39	6·11	486	3310	6·94	8·40	8·41	8·405		8·405	1·32		Standard.
Unthank Road ..	6·390														
Mousehold		3685	40	6·26	423	3262	7·04	1·81	7·80	7·80	1·81	5·99	·94	28·8	New.

NOTE.—Both Cars were driven by the Tramway Company's Inspectors, the weather was wet and the rails more or less flooded. The New Car was about 1½ tons heavier than the old Car. The new Truck was somewhat stiff, but was supplied with Roller Bearings in the Car Journals.

Letter from Mr. Banister, Engineer, Norwich Electrical Tramways, to Mr. Johnson, November 12th, 1906.

In reply to your letter of yesterday's date. I have hardly had sufficient experience to speak with any degree of certainty or authority on the performance of your equipment, but so far as my experience goes, I have found the control of the car to be extremely good, and it is, I think, as smooth both in acceleration and retardation as cars equipped with the ordinary series parallel control motors.

With regard to the Brake. The various trials which I have made on some of the steepest hills in Norwich show that it would be very effective in preventing anything in the nature of a runaway. The operating gear between the solenoid and the brake rod is not altogether satisfactory in some of its details, and we have experienced a good deal of trouble on this account, so that I am unable to say much at present about its performance in regular service. I see no reason, however, why it should not be made a satisfactory service brake. I think perhaps its chief defect is its failure to hold a car, that has been stopped on the up-grade, from rolling back until the brake drum has unwound in one direction and wound up in the other, consequently in stops of this kind the hand-brake must always be used.

I am afraid the above will not be of very much service to you, but at the present stage, with my experience, I should not care to express any very positive opinion, though I see no reason (but quite the contrary) why the equipment should not be entirely satisfactory, both from the efficiency point of view and general service operation.

Yours faithfully,

ALAN N. BANISTER,

Engineer and Manager.

DISCUSSION.

The PRESIDENT (Mr. W. Henry Hunter) said that in offering to the members the opportunity to discuss Mr. Johnson's unique paper which they had had the gratification of listening to, he would like to help them (and particularly the tramway engineers and managers present) to appreciate the position. Mr. Johnson had come from London, but really from New York *viâ* London, and had thrown out a challenge to English electrical engineers. Not being an electrical engineer himself, he (Mr. Hunter) looked to them to respond to that challenge.

He had read through the paper several times, each time with increasing interest and admiration. Mr. Johnson claimed, in the first instance, that the system which he advocated would reduce the operating costs of tramway systems. His experiments in Norwich had shown a reduction of the energy consumption, which varied from 64 to 20%, a fairly wide margin, but he also claimed that the method proposed would provide an immense addition to the controlling power of the men in charge of the tramway car. That was the most important of the claims which he advanced.

They knew what had happened recently in Halifax, and also knew what had occurred on a smaller scale more than once in Manchester and Salford; they were aware that in other parts of this country difficulties had arisen again and again, that accidents had taken place, and that sometimes it had been alleged that the brake failed to act, sometimes that the motorman had lost his head, sometimes other explanations had been offered; but, whatever the explanation, there had been serious and sometimes fatal accidents which remained a blot upon the tramway system.

Mr. Johnson advanced a proposal for overcoming to a large extent waste of energy, an object which commended itself to every engineer, for instead of wasting current in heating useless resistances, he claimed that he returned that current through the motors for the assistance of the generative power of the station.

Mr. J. H. Peck said he had been very much interested in the paper, because although the regenerative system was being generally discussed in the technical papers, it was not until he had carefully studied the author's paper that he had a thorough understanding of Mr. Johnson's system, and whether the conclusions Mr. Johnson had urged were agreed with or not, it must certainly be admitted that the system as a whole was a very ingenious one.

He could well believe, as Mr. Johnson had stated, that the cost of developing this system had been enormous. By looking over this system, and noting the automatic devices and the points in which departures had been made from standard practice, he thought they would hit upon the points which had given the greatest amount of trouble.

When Mr. Johnson and his co-workers undertook the development of a regenerative system, they must have realised that it was an enormous undertaking, as it was a problem upon which a great amount of work had already been expended; in fact, the compound motor was one of the earliest types applied to tramway work, but its use was abandoned, not because it could not be made to work satisfactorily, but because the series motor was simpler, cheaper, and better suited for the severe service conditions. For the same reason, the regenerative system has been abandoned by all the leading manufacturers—*i.e.*, because they felt that the gain resulting from a reduced power consumption and a more economical speed control was not sufficient to

outweigh the greater complications and reduced reliability of the system.

Electricity being such a flexible agent, it was a great temptation to introduce some form of automatic device to overcome any trouble which an inventor might discover in his scheme of working. A few years ago, in switchboard practice, automatic devices were quite the fad, in fact it went to such an extreme that automatic devices were put in to protect other automatic devices, but now—especially in large installations—automatic devices of all kinds were cut out as far as possible, everything being reduced to the simplest possible form, as it was found that, within limits, the fewer the automatic devices, the greater the probabilities of continuous service, and continuity of service was an all-important factor in any system.

The system described appeared to him very complicated as compared with the ordinary series system.

1. In the two-motor equipment there were two armature windings and two commutators in each motor. Everyone who had operated a direct-current motor knew that by far the greater percentage of the trouble was with the commutator and brush gear, and that the part which ranked next in producing trouble was the armature winding. It seemed certain, therefore, that with a motor having twice the amount of brush gear, twice the number of commutators, and twice the number of armature windings, more troubles would be experienced, with a correspondingly increased cost of maintenance.

2. There were four series and four shunt coils, whereas in the series motor there were but four series coils. The shunt coils in the regenerative motor must carry a small current, and therefore are of much finer wire than is required in the field coils of the series motor. They must also be more heavily insulated, and in general the space factor will be much poorer than with the series motor.

3. In the series motor, four terminals are brought out, two from the armature and two from the field. In the regenerative motor, four are brought out from the armatures, eight from the shunt fields, and four from the series fields. Thus there are sixteen leads in the one case, against four leads in the other, and this could be taken as a rough measurement of the relative complications of the two systems.

4. The extra commutator, extra brush gear, increased windings in the armature, four additional shunt coils, all tended to increase the dimensions of the regenerative motor, so that it would be necessary either to manufacture a larger and more costly motor, or to build one of the same dimensions but one which would operate at a lower efficiency and higher temperature; but the ordinary series motor was already operated at practically the heating limit, and while it might be possible to build a motor of larger dimensions which would not run at excessive temperatures, it would be found as soon as it was attempted to build motors of larger capacity, that it would be impossible to find room underneath the car for them.

He could not agree with the author when he stated that the dimensions of the motor would be the same. They could not be the same unless the heating in the motor was increased, and if a higher temperature limit was permitted, greater deterioration might be expected.

5. Two controllers were required instead of one, as on the ordinary equipment. There was also an automatic voltage limiting device, and an extra shaft for use in braking. One of the controllers was called a field changing switch, and was operated by pressing a push button in the handle of the main controller. This might operate without trouble, but the danger of magnetically-operated push button devices is that they are apt to fail to operate when they are most needed.

Another point which affected the efficiency was the increased brush friction which would result from two commutators and two sets of brush gear. This might be quite a serious matter, as it had been found that in certain cases a great amount of heating could be produced by brush friction.

He noted that the gradations in speed were obtained by shunting the field winding of the motor. One of the requirements for a successful traction motor was that it should operate with a very strong field. If the field was weakened, there was almost certain to be trouble from commutation, and the chances of flashing from brush to brush were very greatly increased. It would, of course, be possible to build a motor in which the fields could be considerably shunted, but it meant a larger and more expensive motor.

One of the great features of the regenerative system was that there were four armature windings which could be connected all in series, two in series and two in parallel, or all in parallel. There are a very large number of four-motor equipments in service. It is seldom attempted to make all of these combinations, the reason being that the complications involved are greater than the gain resulting from the better economy.

Mr. S. J. WATSON (Borough Electrical Engineer, Bury) said that the paper which had been presented was of very great interest to everybody engaged on tramway work. The principal point which appealed to him personally was that the author's devices might reduce the tramway output of his station by about one-third, and he felt a little sore on that.

Glancing through the paper, several other points struck him. First, in regard to the saving which the author gave, and the results obtained at Norwich. It would be noticed that in one test the saving was 64%, and in others 15%. It appeared to him that the saving must vary with the gradients which occurred

in any particular district; on a hilly district there might be obtained a very considerable saving, but if a flat district was taken, the only regenerative effect obtained would be on the stoppages, and that could not amount to very much.

He was sorry Mr. J. S. Raworth, another prophet in respect to regeneration, was not present, as it would have been very interesting to have also heard his remarks. Those who read the *Electrical Times* would be very interested in the correspondence a few months ago, first of Mr. Raworth, and afterwards of Mr. Johnson, on the subject.

In regard again to the actual savings on regeneration, in any tramway system assuming they paid for energy 1½d. per unit, if they saved 33⅓%, they would save ½d. Now, the total cost, working expenses, depreciation, interest, sinking fund, and so on, came to about 10d. to 1/- per car mile run, so that the saving would only be about 4 or 5% on the total costs, and against this saving had to be put the extra cost of the regenerative equipment. There were, of course, other savings which the author had not mentioned; for instance, if the regenerative effect was used for braking, there would be a saving on brake blocks and things of that sort, and in the course of a year the saving on these would probably amount to a considerable sum.

There was one other point on which he wished the author had given some information, and that was the cost of the system. There could not be any doubt, as Mr. Peck had mentioned, that the cost of two double-wound armatures, four commutators, the shunt windings, and the controller, must work out appreciably higher than the two ordinary series motor equipment; and as he was not personally engaged on the actual management of tramways, or with the cost of the motor equipment of the cars, he would have appreciated some figures dealing with the difference in cost. He also wished to know what was the effect on a compound-wound generator, if only a few cars were running,

and they all started regenerating when coming down a hill at the same time. What would happen ?

The PRESIDENT mentioned that Mr. Watson had not stated why the regenerative system would reduce the tramway output of the station at Bury by one-third.

Mr. WATSON added that if all the cars at Bury were fitted with regenerative motors, and they were all put into service, and thereby effected a saving of 30 %, the tramway system would be taking 30 % less energy from the power station, and consequently the income from this source would be reduced one-third.

Mr. J. PARRY said he wished to point out that the mechanical brake appeared very short of range, and the wear would probably have to be taken up twice a day.

Mr. GUSTAF LANG stated that as he had assisted the author of the paper with his regenerative system, he would deal with some of the points which had been raised by the various speakers.

He did not quite understand the drift of Mr. Parry's question, but he took it to be a question whether the limits to the movements of solenoids did not interfere with the brake arrangements, particularly after the brake blocks had worn down. The movement of the solenoid had nothing whatever to do with the travel of the brake, *i.e.*, the clearance between the wheels or track and the brake blocks, because that travel was taken up entirely by the spiral, and it was only a question of arranging the spiral and connection between it and the brake lever in such a way that it permitted of a travel which was sufficient to reach, even when the brake blocks were worn off to the maximum extent permissible.

It was rather difficult to explain without an illustration, but Fig. 5 was the best figure at hand for explaining it. From that figure it would be seen that the solenoid pulled on a fine steel wire that was connected to the main cables from the brake spiral. The whole travel of the solenoid which was necessary to cause the spiral to become active, *i.e.*, close down on the shaft or drum was only a matter of an inch or two. After the spiral had closed on the drum, and the friction began to help the original pull on the free end, the travel of the main rope was entirely independent of the solenoid. This would be noted by studying Fig. 5, where it could be seen that whatever length of wire was unravelled from the one side of the spiral, an equal length was wound up on the other side, both lengths corresponding to the total movement of the brake lever at which the wire rope was attached. If then the joints between the main ropes and the fine wire was far enough from the pulley, round which the latter passed, and which was connected to the solenoid plunger to allow either joint to travel unhampered toward the pulley, a distance equal to the total maximum movement of the brake lever, it is evident that the pull of the plunger will remain constant, in as much as the one joint moves equally as much away from the plunger pulley as the other moves closer, and consequently, this motion, whatever it may be, is without influence on the plunger.

Respecting the wish for further details of the test made at Norwich, the instruments used were B.T.H. instruments of 100 amperes capacity. They were connected between the trolley wire and the first circuit breaker.

He could not definitely give the gradients, but he considered the route a fair average. From Mousehold to Cavalry Barracks there was a very steep gradient. From Cavalry Barracks to Post Office was a slight gradient, about half of it was a slight down gradient, and the other half a slight up gradient. From

Post Office to Unthank Road terminus it started fairly level, and then went on up a gradient, then for a distance of about a quarter-mile it was practically level, and another very sharp up gradient, 1 in 12, this was only quite short, and from there onwards it was practically level to the end of the road.

From the table it would be noticed that the largest saving was when coming downhill. The different readings given should not be looked at singly, *i.e.*, going only one way, but the four last set of figures should be studied. These figures gave the results for a round trip for each part of the route; and of course it was only a round trip that counted and had any direct interest, because the result going downhill did not mean anything except when taken together with the current consumed going up that same hill. Consequently, on the very steep gradient from Mousehold to Cavalry Barracks and back again there was a saving of 31·8%, on the slight down grade and up grade Cavalry Barracks and Post Office there was a saving of 27%, and from Post Office to Unthank Road a saving of 27·9%, which, of course, averaged 28·8% for an average route of 3·2 miles in length single journey.

It would have been of great interest to have had a profile of the road so as to show exactly the gradients, but he had not been able to get a drawing ready in time.

Two speakers had referred to the increased maintenance and increased heating of the motors. Now, there were several points which he thought had been overlooked by these speakers, as, for instance, the fact that in avoiding the use of resistances and adopting the double series parallel principle, evidently the total efficiency of the equipment, as such, must be somewhat higher, or rather considerably higher than the efficiency of the ordinary equipment, particularly during the time of acceleration. The difference could, of course, be proved by calculations. He had therefore calculated the efficiencies for a standard equipment,

and for an equipment on the lines described in the paper, and found that with the motors used at Norwich a saving during accelerating period of about 15 % would be accomplished. This was demonstrated in the Norwich test, and could be seen from the table by comparing the kilo-watt hour inputs for the standard car with that of the new car over the same journey. For instance, going up from Cavalry Barracks to Mousehold, the input for a standard car was 1·5, and the input for a new car 1·39. Taken on a down grade, it was more difficult to get a fair comparison on account of the drivers handling the standard car in so many different ways, some putting on current each time they start, others with more experience took off the brake and allowed the car to accelerate gradually, and consequently, they did not waste so much energy in braking.

He had found from his experience that the best results for comparing inputs were attainable on up grades, where the differences in the driving were practically eliminated.

The saving during acceleration undoubtedly put the regenerative equipment in a better comparison with the standard equipment, because the losses necessarily were less and consequently there was a margin left for heating during regeneration.

Electric rheostatic braking had been used during the last few years, and not many complaints had been heard about the overheating of the motors. In a rheostatic equipment the current through the motors depends entirely on the motor men, and he had particularly noticed that the drivers were liable to to use the brake in rather a rough way, which meant that very large currents had to flow through the armatures to the resistances, larger currents in fact then would be experienced with regcnerative equipment where the series winding was in opposition to the shunt winding.

He did not know whether it was clear that by having the series winding, the current regenerated was more or less limited

to a maximum value which could be adjusted to anything required.

He was of opinion that taking into account the saving due to the higher efficiency of the whole equipment, and the fact that a large rush of current could not take place in the regenerative system, the increase in heating on account of using the motors for regenerative braking and considerably less than in a rheostatic equipment.

As regards maintenance of contacts and the like, he was of the opinion that the wear of the contacts was mostly due to burning, and consequent filing of the contacts. Being due to those causes, it was evident that if less current was handled on each contact, there would be less burning of the contacts, and therefore less wear on them.

In using four armature circuits, necessarily there would be more contacts; but on the other hand, each contact had not to carry the same amount of current as the contacts would have to carry in an ordinary series parallel equipment for the same input. Therefore, the calculations made on the increased maintenance of the controller contacts, and commutators, etc., were not quite correct.

Mr. Watson had remarked about the efficiency of regeneration when on a level road where the hill potential was practically absent. Of course, that question entirely depended on how many stops were made in a mile; if a great number of stops, say eight per mile, were made on a perfectly level path, the regeneration would be quite considerable. It would be found with eight stops per mile that a regeneration of roughly 20% could be obtained; in addition, with this equipment the frequent acceleration and retardation was most favourable, because the higher efficiency during the acceleration period added a considerable saving to that due to regeneration. Therefore, on the

whole, a frequent service on the level gave equally good results as a less frequent service on hilly routes.

A question had been asked why double paralleling was not used on ordinary four-motor equipments. This was rather evident, if it was kept in mind that by double paralleling the gain would be only 10%; the complications then would not be covered by the saving, whereas, if by introducing the double-series paralleling, not only a saving was obtained of 10% due to the double-series paralleling itself, but also the possibility of utilising the motors for regeneration was created, the gain would become so great as to render the complication of double-series paralleling of very little importance compared with the saving. If the same saving could have been accomplished only by double-series paralleling the motors, there was, in his opinion, no question but that the double-series paralleling would have been adopted before this.

Regarding the maintenance of brush gear, he was of the same opinion as he expressed in respect of the maintenance of contacts and the like—*i.e.*, that as the brushes had to carry smaller currents, and consequently sparking at the brushes would be reduced, the maintenance must be less. It was evident that when the current was divided on four commutators the reactance voltage (which was more or less the determining factor of the sparking) would be considerably reduced, and also the current itself on each commutator would be less.

It appeared to him that in the modern practice and development of the brush gear for direct-current motors, such improvements had been made that the brushes and the commutator did not give any more trouble than any other part of the motors. The machines nowadays were constructed with a much lower reactance voltage, and the sparking had been so much reduced that the pressure on the brush could be considerably less, and consequently the wear on the carbons could not be very great.

It had been a very difficult matter to avoid the decrease of the space factor in the shunt coils, but it had been accomplished by using, instead of ordinary wire, which gave a very low space factor, flat copper band with very thin insulation in between the copper strip, whereby such a considerable saving was made that the space factor of the shunt coil compared very favourably with the space factor of the field coils of ordinary series machines.

In respect to automatic devices, he only wished to call attention to the fact that the multiple-unit system employed, not one, but a considerable number of automatic or semi-automatic switches. Instead of using a button switch, they use a controller to make the connection to the automatic switches—viz., they had a controller instead of the push button in the handle. He, therefore, did not see any reason why the simple solenoid in the field changer should not be as reliable as the solenoid of the multiple-unit system, in which a considerable number of solenoids had to be dealt with on each car.

Very few complaints had been made about the contactors (the technical term for the solenoid switches in the multiple-unit system) getting out of order, and the general adoption of the multiple-unit system showed very clearly that those complications were not at all a very serious matter.

The PRESIDENT (Mr. W. Henry Hunter) said that the criticisms up to that point had been directed entirely to the question of the manufacturing point of view, the question of current and costs; but nobody had dealt with the claim advanced in the paper, all-important from the tramway users' point of view, of safety in brakage.

Mr. ALFRED SAXON communicated to the meeting a few remarks bearing on the tramway system in Cincinatti.

Mr. E. H. JOHNSON, in replying to the remarks of the various speakers, said that they were well aware of the fact, without him telling them, that inventions of the character mentioned in the paper were always met by unlimited reasons and arguments put forward by those who were responsible for the existing order of things. He had had those arguments put before him whilst acting as Mr. Thomas Edison's representative for many years in the introduction of the electric light, the telephone, and the trolley systems in England and America; he had had in these labours the same experience as he was now encountering, the same line of arguments were presented, and had to be met in exactly the same way that the arguments now presented would have to be met—viz., by putting the system into practical operation, and so proving his contention respecting it. That, in fact, was what they were now doing.

The questions asked had covered every point that was made in the paper, and he thought that if the paper was carefully read, the gentlemen who had put the questions would find them already answered. It was apparent that on several points raised a good deal of mis-reading had taken place. One was that he claimed to save 25% of the cost of operating. No such claim was made in the paper, what was spoken of as "saving" was saving in energy consumption. The cost of this energy depended on a good many considerations. The "saving" which was effected by the system was moreover not confined to saving in energy alone; it was very great in many other directions. He had not elaborated on these items, but thought he might now mention that the saving in wheels and brake shoes through regenerative braking would be found quite sufficient alone to compensate for all the extra cost of maintenance imposed by the additional parts that had been incorporated in the system.

In regard to the watt meter readings, the watt meters were simply adjusted to read exactly alike under like conditions, and

as they were used for testing the cars comparatively, it did not make much difference whether the watt meter read watts correctly so long as they read like units on both cars, and thus afforded a true comparison.

As regards double-series paralleling, Mr. Lang had answered that point; but to the question put by Mr. Peck as to why double-series paralleling was not used on equipments where four motors were now used, his answer was, that while it was true that in double-series paralleling a saving was effected in the energy input, that saving was in itself not sufficient to justify the added controller complications, but when to such saving was added the 25 or 30 % of energy returned by regeneration, a point was reached where it becomes sufficiently remunerative to justify the more complex equipment.

As to skidding, that was a serious problem, and one which was before all tramway engineers alike. The most serious problem before the electrical engineer undoubtedly arises from the fact that the weight of the tramcars had greatly increased, while the gradients upon which they were operated remained unchanged. He thought he had solved that problem at Norwich in a satisfactory way by applying his spiral friction device to both wheel shoes and the track shoe, thus dividing the frictional pull between the two, thereby imposing an insufficient friction on the wheels to cause them to skid.

One speaker—he thought rather from inadvertence than from misconception—spoke of the use in the regenerative system of two armatures in the motor. Of course, there was only one armature in each motor, but the windings of that armature were divided, and two armature circuits were thus obtained. As regards the brushes and the brush holder, it should be borne in mind that in dividing the windings of the armature, the duty of the brushes and of the commutator was also divided, consequently the rate of the brush wear and of the commutator wear would be

reduced, and the aggregate wear very likely not materially increased.

Reference had been made to the difference in the weight of the cars at Norwich, one being 1½ tons heavier than the other. The speaker who made that reference "thought" he knew wherein this difference lay, but he (Mr. Johnson) would tell him, which was probably contrary to his impressions, viz., that the motors used as regenerative motors were lighter than the standard motors of like horse-power, and that the difference in weight alluded to was due to a new truck which was being introduced.

He did not intend it to be understood from this that they got the greater amount of work imposed by regeneration from the same weight of motor employed for propelling alone, because, whatever was regenerated was necessary additional duty put upon the motors. But this added duty was not in the direct ratio of the regenerative duty, since through double series paralleling the *input* was less, and the total increase of duty was thus made small. To increase the motor capacity in order to take care of the small increase of resultant heating would in any event be an infinitesimal item of cost.

One speaker had mentioned that the regenerative idea was not new, and was practically as old as the motor itself. His reply to that was that he was quite aware of this fact, and that which was advanced in the paper as new was only that a practical worked-out system of realising what had been until then more or less of an inventor's dream was now for the first time made available.

Respecting the failure of automatic devices, he thought if they looked carefully into the system mentioned, that they would find that the automatic feature applied to the "field changer" was so arranged as to cause its failure to operate to simply deprive the car of its generating function, and not of its propel-

ling function. As a safety factor the automatic principle was of the utmost importance, the automatic characteristic of the brake, for instance, was that it was like a burglar alarm "set to danger," as, when anything went wrong, it came into action by the failure of its energizing potential, instead of the application of energy to it. The brakes were in the present case held off by the presence of the electric current, if that current failed the brakes came on without the volition of the driver. If this was not the function that was required in case of an accident to a tramcar, or where the motorman "lost his head," he (Mr. Johnson) would like to know what was.

The PRESIDENT (Mr. W. Henry Hunter) said he wished to express his thanks to the author for his admirable paper, and for the great kindness and trouble which he had shown in coming down to read it. He had done them an honour, and had conferred upon them a favour, and they were his debtors to that extent. He therefore proposed that they should give Mr. Johnson their very best thanks.

Personally he thought the paper had been educational, and they all knew that especially amongst youthful members of the community, educational methods were not always popular, youth hardly took kindly to education, it was always when people became of mature years that they were willing to learn.

He had been asked to request Mr. Johnson if he would kindly add to the statements given regarding the tests at Norwich, for insertion in the Association's Proceedings, a sketch showing the track at Norwich with the gradients and stopping places. That would make information relating to the test complete. Also to ask for particulars of the comparative tractive force required on the level with the old car and the new. The special reason the latter was required was that it was noted that in the Norwich test the new car had roller bearings, while the old car was not

so fitted. Roller bearings diminished the tractive force required for moving any vehicle while new; when they were not new perhaps they made a difference the other way. This information would make the interesting statements respecting the Norwich tests complete.

He also hoped Mr. Johnson would be able to add some particulars about the Blackburn tests, and thus the record would be complete.

Mr. Hunter then proposed a vote of thanks to Mr. Johnson for the paper, and said he would ask the ex-President, Mr. Matthews, to second it.

Mr. ROBERT MATTHEWS said that it gave him the greatest possible pleasure to second the vote of thanks. He sympathised with the author for the critical way in which some of the speakers had criticised the paper; at the same time, it was good for the Association that those critics, whether good, bad, sound or unsound, came to the meetings; they were always educational. The paper had given him the greatest possible pleasure, and he was indebted to Mr. Johnson for it; he greatly appreciated his kindness, and that of his assistant, Mr. Lang, for their trouble.

Mr. HENRY WEBB said he would like to add his thanks to Mr. Johnson, because it was at his (Mr. Webb's) instigation that he came here to give the paper. He had told Mr. Johnson that Lancashire people were in the habit of expressing their opinions freely, and very different to the way they did in the London discussions. He was disappointed that the members had not risen to the occasion or to their usual level, but probably that was due to their depending upon their stranger friends, who had not cared to go so thoroughly into it.

It would be admitted that Mr. Johnson knew something of his business. A man who had been twenty years in the laboratory

of Mr. Edison, a man who had to bring Mr. Edison's electric light before the British public, also the trolley and the telephone, must know something about it; and he therefore hoped that his efforts in the regenerative system would not only redound to his credit, but would cause it to be a great and universal system having Edison's new batteries and Johnson's regenerative system.

Mr. JOHNSON, in replying to the vote of thanks, said that it was unnecessary for him to say that the expression of goodwill was extremely gratifying to him and was appreciated to the full. He could assure them that instead of it being a trouble it had been a great pleasure for him to be able to respond to Mr. Webb's invitation to come down and meet his fellow citizens, and talk upon any subject upon which Mr. Webb thought he (Mr. Johnson) might be able to say something of interest.

He would like to say in regard to the President's suggestion that he should add something to the paper in the way of test data, that the particulars of the test at Norwich which he had presented were particulars of a preliminary test only. He would now add that the experts of some of the largest companies had taken possession of the tests, and were going to conduct a series of tests of an exhaustive character, to determine finally as to whether there was, or was not, "anything in regeneration"; and further, that an expert from America would be present, and would watch the practical operation of the cars for a month or two, to learn what the maintenance factor really amounted to.

When those tests were completed, he would file with the Association a profile of the road, all the data, and a full copy of the results attained, and the conclusions reached by the experts, irrespective of whether they were good, bad, or indifferent.

ADDENDUM.

In accordance with a desire expressed by the President of the Association, and a promise of the author of the foregoing paper to comply therewith, the following data and expert deduction therefrom, obtained by further tests at Norwich, and at Solingen in Germany, are respectfully submitted for publication with the paper as read at the meeting.

NORWICH TESTS.

The tests previously obtained were recorded by means of registering watt-meters. It is interesting to note that despite the general disbelief in the accuracy of these instruments, they are in this case at least shown to have been quite reliable. Their verification was effected by further tests of the same equipment over the same route, made by means of new and sensitive recording volt and amp. meters. These latter instruments were rendered exceptionally accurate by being independently excited by means of accumulators.

This elaborate testing outfit, quite new and up to date, is interesting, and deserves special mention. The needles work in a horizontal plane, and are damped electro-magnetically. Five-second intervals are indicated by means of capilliary pens operated by magnets through the medium of a relay under control of clockwork. The speed is also indicated by an electro magnetically-controlled pen, the record indicating each revolution of the wheel through the medium of contacts on the axle. The wheel diameter thus becomes a unit of distance, as the five-second interval becomes the unit of time.

The Plates III. and IV. give curves of speed and energy consumption on the basis of time, and also a profile of the route.

COMPARATIVE RESULTS.

OUTWARD JOURNEY.

		Watt Meter.		Volt and Ammeter.
Time	=	976 (seconds)	.....	957
Input.....	=	2·50 (K.W.H.)	.....	2·44
Output	=	·30	.....	·287
No. of stops	=	13	.....	16

INWARD JOURNEY.

Time	=	1,016	.....	996
Input.....	=	1·73	.....	1·71
Output	=	1·60	.....	·594
No. of stops	=	11	.....	18

The difference in the number of stops is balanced by a difference in the weight of the car trucks. This amounted to 1,400lbs., in favour of volt and ammeter test. These differences are considered to practically balance each other, and may therefore be neglected.

The consistent paralleling of these separate tests justifies the conclusion that a fair average result has been obtained. These and other tests of a comparative nature have strikingly illustrated the fact that the regenerative system is much less liable to fluctuation from handling than is the non-regenerative; it has, in fact, been found necessary to make several runs with the non-regenerative, and to employ various drivers in order to get a fair mean result, whereas with the regenerative, a uniform result is always obtained.

In consequence of this need of obtaining an average of the non-regenerative, and of the excessive elaboration and calculation demanded by the volt and ammeter tests, it was thought best to rely upon watt meter tests of the non-regenerative. An average of these for a week was therefore taken, and is assumed to fairly represent the energy consumption of the standard non-regenerative system.

In consequence of a difference of speed amounting to 11% against the regenerative system, an allowance is made by an

increase of the current consumption of the non-regenerative by 3%. The weight of the cars and of the passengers carried was practically the same.

In these circumstances, the current consumption of the standard car was 1·184 units per car mile; that of the regenerative was ·865, thus showing a saving of 27%.

SOLINGEN TESTS.

Results corroborative of the Norwich figures were obtained with similar equipment in Solingen, Germany. A profile of the route over which these latter comparative tests were made is herewith submitted. Plate V.

In the Soligen tests, watt meters were used in one instance, three runs being made with each car on one and the same day, the net input being noted at each stop. Other tests were made with less elaboration, but confirmed the results of the first. The drivers of the standard cars were naturally more familiar with their equipments than was the driver of the regenerative car, and were therefore in a position to favour their equipments. After the first journey of the standard car, the driver was instructed to run his car more economically, and there is no doubt that in doing so he ran at a lower speed subsequently, and at a lower speed than the regenerative car was run at any time. The time between stops was not noted in this test, hence the comparison is not quite a true one. Plate VI.

The average net input of the respective cars for the three runs of the first-mentioned test was as follows:—

		Input.		Time.
Standard.....	=	3·37	.....	986 seconds.
Regenerative ...	=	2·21	.....	994 „

thus showing a net saving of 34·4%. Taking the grand average of the total runs—*i.e.*, seven of the regenerative and six of the standard, the net saving works out as 30%.

MAINTENANCE.

Since this factor of the regenerative system seemed to be of very special interest to the critical members present at the reading of the paper, some effort has been made to acquire data and expert opinion regarding it. Of course, the system has not yet been in operation long enough to supply positive data, or even to enable the expression of positive opinion, but enough has been observed by competent experts to enable them to speak with conviction on all the points involved.

The following comparative estimate of costs of maintenance has been made by most competent and entirely disinterested experts in traction work. For the purpose of this comparison, the actual costs of the standard system at Norwich has been taken, it being found that this represents a fair average.

Because of the small use made of mechanical brakes in the regenerative system, it is held to be conservative to put the brake renewals at about one-third of the cost of those of the non-regenerative system.

Taking the classification in use at Norwich—viz., "mechanical and electrical" repairs, it is held that, as regards the mechanical, the regenerative costs will not be greater than those of the standard system, but that, because of the greater number of commutators, brushes, and field and armature leads the electrical repairs will be greater.

After making due allowance for the smaller currents dealt with, it is held that this branch of the up-keep costs will be 50% higher than that of the standard series system. Experience has shown that for a given size of motor equipment, the cost of controller and lead renewals is in direct proportion to the number of fingers and segments employed in the controllers.

The total number of fingers and segments employed in the regenerative controllers, inclusive of the field changer, is about 150% greater than in the standard as employed at Norwich, but

after taking account of the small currents handled by the regenerative controllers, as well as the limited movement of the field changer, it is believed that an increase of 75% would be a fair charge against the regenerative equipment on this score. Based upon these assumptions, the following table of comparison has been agreed upon:—

PER CAR PER ANNUM.

	Regenerative. £ s. d.		Non-regenerative. £ s. d.
Brakes	2 14 5	.....	8 3 2
Motors, mechanical	2 15 5	.....	2 15 5
Motors, electrical	7 13 10	.....	5 2 7
Controllers and car wiring...	5 1 6	.....	2 18 0
Total	£18 5 2	.....	£18 19 2

The conclusion, therefore, is that a debit and credit account as between the regenerative and non-regenerative system will result in a very close balance in the item of upkeep costs of the equipment *per se*, but, as pointed out in the paper, there will be a substantial difference in favour of the regenerative when the system as a whole is considered.

EQUIPMENT COSTS.

In estimating the cost of the regenerative equipment, it is assumed that they will be manufactured under like conditions with the standard as regards quantities, methods, etc.

These estimates have been made under the supervision of experienced manufacturers, and err, if at all, on the side of conservatism.

Without going into the detail figures, it may be stated that the cost of a regenerative equipment works out at about £350, as against £225 for the standard.

As by far the largest field for the regenerative system will be in its substitution for the old standards, much consideration is given to the question of loss consequent upon scrapping old equipment. It is estimated that these, inclusive of old motors,

controllers, cables, etc., etc., will not realise more than £40, which figure is accordingly taken.

OPERATING COSTS.

In the following calculation of saving in operating costs, as in the estimates of the cost of equipping, no account is taken of the saving in capital investment in power plant, feeder copper, etc., or the consequent saving in the items of labour, depreciation, insurance, oil, waste, etc., etc. It has been stated by competent authority that this reduction of capital outlay is in direct proportion to the saving in energy consumption. Manifestly if this great saving was taken into account, the estimated savings per car per annum which are given in the table following would appear to still greater advantage.

This omission has been purposely made in order to render the table more attractive to the tramway manager, who, having his power plant already built, seeks only to find out what saving he can effect in the operation of his cars by substituting the new system. Since his cars will consume less energy, it will be manifest to him that he can put on more cars without increasing his plant, and the consequent capital outlay. The value and importance of this fact may be safely left to him in the case of substitution, or to the supervising engineers, in the case of new codstruction.

In estimating the actual saving per car per annum when regenerative equipments are used in new installations, it is necessary to substract from the monetary value of the saving the additional interest on capital outlay—*i.e.*, £350 less £225 = £125, and the additional depreciation—*i.e.*, on £125.

When substituting regenerative equipments for old ones, part of the cost of replacement is borne by the sinking fund on the old equipments. Consequently, the additional interest chargeable to the saving is the interest on the difference between the actual

cost—*i.e.*, £250 less £40 = £310, and the value of the sinking fund at the time.

The additional depreciation will, in this case, as in the first, be on the difference in the value of the new and the old equipment—*i.e.*, on £125.

On this basis the accompanying curves (Plate VII.) are calculated under the supposition that a saving of either 20 or 25% can be effected, that each car is used three hundred days in the year during fourteen hours a day, and that it covers 6·5 miles an hour on an average. This would mean that each car covers 27,500 miles a year, a very conservative estimate.

Each curve sheet corresponds to different current consumptions per car mile with respectively 20 and 25% saving. The three curves on each sheet indicate the nett saving in pounds per car per annum at the different values of ¾d., 1d., 1½d. per unit of electrical energy, and under the assumption that a change is made in the equipment after the standard equipments have been used a certain number of years—from 1 to 18—and that at the end of these periods 4 per cent. of the value of the old equipments has been paid into a sinking fund which has been compounded at 4% interest.

It will be seen that a value of 1d. per unit and a present current consumption of 1·8 units per car mile, on which a saving of 25% is effected by the substitution of regenerative equipment in place of a ten years old standard equipment, a nett saving per car per annum of about £38 10s. will be made. If the regenerative equipments are used in place of standard equipments in a new installation, a nett saving of £41 10s. per car per annum would be secured.

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7 Plates follow illustrating this Paper.

E THIRD FUN

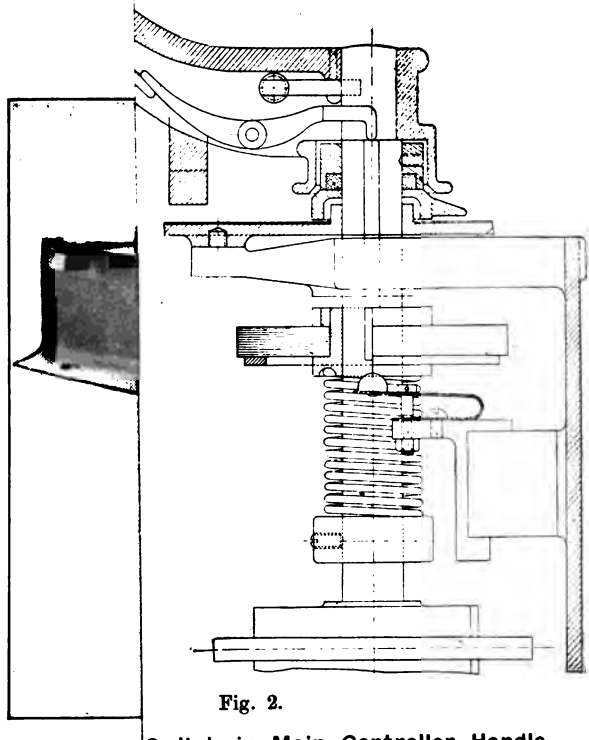

Fig. 2.

Switch in Main Controller Handle.

51ST Annual Report

OF THE COUNCIL,

1906.

MANCHESTER:
HERALD & WALKER, POOL FOLD CHAMBERS, OFF CHAPEL WALKS,
1907.

COUNCIL.

1907.

President:

Mr. W. HENRY HUNTER, M.Inst.C.E.

Vice-President:

Mr. ROBERT MATTHEWS.

Treasurer:

Mr. FRED WALTHEW.

Trustees:

Mr. T. ASHBURY
Sir W. H. BAILEY
Mr. J. WEST
„ HENRY WEBB
Mr. E. G. CONSTANTINE.

Mr. M. INGRAM
„ JOS. BUTTERWORTH
„ H. BATES
„ H. E. GRESHAM
„ GEO. SAXON
Mr. DANIEL ADAMSON
„ H. N. BICKERTON
„ A. ETCHELLS
„ FRANK PEARN
„ F. W. REED

Librarian:

Mr. R. GASS,
343, Hyde Road, Gorton.

Secretary:

Mr. FRANK HAZELTON,
39, Brown Street, Manchester.

Annual Report of Council,

1906.

The Council have pleasure in presenting the 51st Annual Report of Proceedings.

To the membership roll during the year have been added—

33 Members,

and, after taking into account the loss by death, resignation, and erasure, the total number of names of members on the roll amounts to 547, as against 542 in the previous year, namely :—

20	Honorary Life Members.
304	Members.
223	Members (entitled to Financial Benefit according to Rule 7.)
Total 547	

Upon reference to the Financial Statement, as certified by the auditors, it will be seen that the balance standing to the credit of the Association, after payment of all accounts due up to the 31st December, amounts to £5,514. 18s. 8d., as against £5,437 7s. 11d., at the close of the preceding year, thus showing a surplus over expenditure of £77. 5s. 9d. on the year's working.

Superannuation Fund.—At the commencement of the year there were nine superannuitants; one died during the year, making the total number eight, who are receiving 8/- weekly.

It is with sincere regret the Council have to record that during the year death has removed the following Members :—

Bates, John - - - -	Manchester.
Craven, William - - -	Manchester.
Knowles, William - - -	Salford.
Mathewson, J. E. - - - -	Altrincham.
Rendell, Samuel - - -	New Mills.

Rodger, David	Barrow-in-Furness.
Sykes, Ezra	Huddersfield.
Webb, F. W.	Crewe.
Whitehead, Thos.	Manchester.

The following gentlemen have resigned their membership during the year:—

Aspin, J.	Glasgow.
Craven, Thos.	Manchester.
Hardisty, John	Manchester.
Harper, E.	Manchester.
Loud, H. S.	U. S. A.
Mac.Gregor, Jas.	Sheffield.
Mellanby, A. L.	Glasgow.
Neilson, R. M.	Hartlepool.
Vickers, Geo.	London.
Rufus, G.	Manchester.

The following gentlemen have ceased to be members during the year:—

Charlesworth, S.	Oldham.
Hewitt, C. J.	Prescot.
Holland, R. S.	Glossop.
Muddiman, J.	
Schofield, Jas.	Heaton Mersey.
Taylor, R. P.	U. S. A.
Whittaker, W. T.	Manchester.
Tipton, E.	Manchester.
Williamson, Jos.	Manchester.

Papers Read and Discussions Held.

Jan. 13.—"Paper" by Mr. Samuel Rendell, Manchester; "The Steam Locomotive Fifty Years ago and now."

„ 27.—"Paper" by Mr. G. F. Metzger, Manchester; "Modern Electrical Developments."

Feb. 24.—"Paper" by Mr. W. H. Cook and Mr. Joseph H. Stubbs; "The Textile Industry."

Mar. 10.—"Paper" by Mr. H. N. Bickerton, Ashton-under-Lyne; "Gas, Oil, and Petrol Engines."

,, 24.—"Paper" by Mr. W. Henry Hunter, Manchester; "Harbours, Docks, and their Equipment."

Oct. 27.—Inaugural Address by the President, Mr. W. Henry Hunter, M.Inst.C.E.

Nov. 10.—"Paper" by Mr. M. Ingram, Manchester; "Engineering Developments in a Social and Industrial Evolution."

,, 24.—"Paper" by Mr. E. H. Johnson, London; "The Third Function of Electric Traction Motors."

Dec. 8.—"Paper" by Mr. William G. Gass, Bolton; "Construction of Centrifugal Pumps."

CONSTANTINE MEDAL.

The Gold Medal for the Session 1905-6 was awarded to the authors of the paper on "Textile Industry," Messrs. Jos. H. Stubbs and W. H. Cook.

The Council desire to convey their sincere thanks to the many members who by the reading of papers, contributing to the discussions, or in other ways have assisted in the work of the Association, and finally to the President, Mr. W. H. Hunter, for the courtesy and ability he has at all times displayed in conducting the business of the Association, and for the hospitality he has on various occasions extended to the Members and Ladies during the year.

ANNUAL GENERAL MEETING, MARCH, 1906.

PROPOSED ALTERATION TO RULES.

In accordance with the convening circular various proposed amendments to rules, principally in regard to the suggested inclusion in the Association of two additional classes, namely,

Associates and Graduates were considered. The result was as follows :—

Officers.

Rule 1.—That the sixth paragraph be deleted and the following paragraph substituted :—

> "The President shall hold office for one year only. Other retiring Officers shall be eligible for re-election, except such Members of Council as have served two years consecutively who shall not be eligible for a period of twelve months."

Meetings.

Rule 3.—That the sentence commencing with "shall be, etc.," in the first paragraph, be deleted, and the following sentence be substituted : —

> "Shall be held on the second Saturday in June, September and December, and the last Meeting in March, which shall be the Annual Meeting."

Admission of Members.

Rule 4.—That the first paragraph be deleted and the following substituted :—

> "Candidates for admission as Members must be persons not under 25 years of age, who shall have been engaged as Employer, Manager, Foreman, or Leading Draughtsman in one of the branches of the Engineering Trades for a period of three years. The Council, however, shall have the power to nominate any gentleman whose attainments in scientific or kindred pursuits are such as would, in their opinion, if elected, further the interests of the Association."

Associate Members and Graduates.

Thereafter, a long and exhaustive discussion ensued in regard to the remaining proposed alterations on the Agenda, with special reference to the inclusion of two new Classes of Members to the Association, namely, Associate Members and Graduates. From this discussion, it was very apparent that as regards the inclusion of these new Classes, the views of the members were exceedingly diverse, and ultimately the resolution in respect to the inclusion of Associate Members was

put to the Meeting, with the result that 39 voted in favour, and 47 against. The motion, therefore, was rejected.

In view of this vote, it was not deemed necessary to further proceed with the amendments in regard to Graduates.

PRESIDENTIAL SOUVENIR OF THE JUBILEE YEAR.

At the conclusion of the formal business of the Annual General Meeting, Mr. Alfred Saxon (Ex-President) in a few appropriate words, referred to the interesting year which had just passed, and to the great efforts made and generosity displayed by the President (Mr. Matthews) to make this, the Jubilee Year, worthy of the Association. He said that as already notified to the members, it was the unanimous feeling that a Souvenir of this important year should be presented to Mr. and Mrs. Matthews, and this suggestion had been heartily taken up by the council and members, with the result that they were enabled to present to Mr. and Mrs. Matthews the beautiful Souvenir exhibited on the table before them. Thereafter, Mr. Thomas Ashbury, after an interesting speech, asked the President to accept a Silver Gilt Casket containing an Illuminated Address in expression of the members' appreciation of his acceptable services for the past year, and as a Souvenir of the Jubilee year of the Association.

Subsequently other members of the Association expressed their esteem and respect for the President, which were cordially approved by all the members present.

The President (Mr. R. Matthews) in a few sentences expressed his appreciation for the beautiful Souvenir and Address which had been presented to him, and said they would form an heirloom in his family for he hoped, generations to come, and

be in evidence not only of the Jubilee of the Association, but also evidence of the way in which he had been treated by the members during his year of office.

The Silver Gilt Casket containing the Address is a very fine example of the silversmiths' art. The workmanship is of a first class order, the idea and modelling of the figures and different parts being exceptionally fine. At each of the four corners are seated figures typical of Commerce, Industry Scientific Research, and Engineering; in front and at back of casket are prows of ships supported by dolphins, emblematic of the connection of Manchester with the sea. On the front of the casket is a very fine enamel view of the Manchester Town Hall, a corresponding panel on the other side of casket contains an enamel of the School of Technology. A shield containing the following superscription appears immediately beneath the enamel view of the Town Hall:

> "The Manchester Association of Engineers. Presented to Robert Matthews, Esq., in commemoration of his Presidency during the Jubilee Year of the Association, March 31st, 1906."

At either end of the casket are representations of the Arms of the City of Manchester and the badge in use by the Manchester Association of Engineers. On the other cover are shields bearing the initals R. M. and J. M. The dome of cover of casket is quite a departure from works of this class. By the introduction of a very fine crystal and four enamelled globes a splendid effect is obtained. A beautifully modelled figure of Progress surmounts this part. The casket is enriched with representations of the Lancaster Rose. A pleasing effect is obtained by a sparing use of decoration, a judicious use of plain spaces, and excellence of outline.

The Illuminated Address is a finely executed piece of work, and reads as follows :—

To

ROBERT MATTHEWS, ESQUIRE.

The members of the Manchester Association of Engineers hereby desire to express to Robert Matthews, Esq., their high appreciation of the valuable services he has rendered as President during the Jubilee Year of the Association, and on his retirement from the Chair they most heartily wish him and Mrs. Matthew, who has so gracefully supported him during his year of office, health, prosperity and every blessing, and as a Jubilee Souvenir they request his acceptance of this Address and the Casket for its reception.

Signed on behalf of the Subscribers,

THOMAS ASHBURY.	HENRY WEBB.
W. H. BAILEY.	W. FOX.
EBENEZER MARSHALL.	JOSEPH BUTTERWORTH.
THOMAS ROBERTS.	JOSEPH H. STUBBS.
JOHN WEST.	WILLIAM INGHAM.
E. G. CONSTANTINE.	ALFRED ETCHELLS.
FRED WALTHEW.	HERBERT BATES.
M. INGRAM.	WILLIAW H. COOK.
ALFRED SAXON.	FRANK HAZELTON.

March 31st, 1906.

The whole of the work was designed and executed by Messrs. Elkington & Co., Ltd., Manchester.

During the year various Excursions and Social Gatherings have taken place, short accounts of which are given hereunder.

JUBILEE DINNER.

FRIDAY, FEBRUARY 8TH, 1906.

The Fiftieth or Jubilee Anniversary Dinner of the Association was held on Friday evening, February 9th, at the Midland Hotel, the attendance numbering 330 Members and friends. The President (Mr. Robert Matthews) occupied the Chair, and he was supported by the ex-President (Mr. Alfred Saxon), and, amongst others, the following Guests :—

The Lord Mayor of Manchester.
The Mayor of Salford.
Sir William H. White.
Sir John Durston (Engineer-in-Chief, Admiralty).
Sir William Mather.
The Master Cutler (Mr. Sydney Robinson).
Mr. H. F. Donaldson (Royal Ordnance Factories).
Colonel H. C. L. Holden (Royal Gun Factory, Woolwich).
Dr. R. T. Glazebrook (National Physical Laboratory).
Mr. J. A. F. Aspinall (L. & Y. Railway).

In responding to the Navy, Army and Reserve Forces, Sir JOHN DURSTON, after some general remarks, said that Manchester Machine Tools were recognised as the standard of excellence throughout the world. His personal experience of their good qualities covered an extensive period, for it was nearly 45 years since he became acquainted with a Whitworth lathe. His experience was also the universal experience of Naval Engineers, and he recognised the superiority of machine tools by purchasing them in large quantities, and "the memory of man runneth not to the contrary." He referred to the influence the Ship Canal was likely to have on the future of Manchester, and said that if it had been made a few feet deeper it would have enabled them to equip the largest battleship in the service. Colonel HOLDEN also responded.

Dr. HOPKINSON proposed "Our Municipal Institutions," and alluded to the local great success in electrical manufactures, which was responded to by the LORD MAYOR OF MANCHESTER and the MAYOR OF SALFORD.

Dr. GLAZEBROOK proposed success to the Engineering Trades, and said it was good to be optimistic, especially as applied to these trades. The connection between the laboratory, of which he was a Director, and the engineer was increasing, and he was glad to say that they had received great assistance from the boilermakers of Lancashire. When he remembered that their Institution was to promote Engineering science, he realised very fully that it was not by optimism or hard work alone, but by well thought out reasoning, and well thought out knowledge, and their application to science that Manchester became the centre of the trade. All the efforts he could put forth in the laboratory would be valueless if he had not the co-operation of the engineering profession. He paid a graceful compliment to the valuable services rendered by Sir William Mather during the past 40 years, which was endorsed by the Chairman, who said that Sir William was one of the first and greatest benefactors the Association had had.

Sir WILLIAM MATHER responded, and his remarks were reminiscent of the Association 40 years ago, when it was more of a Social than an Engineering Society; he said the provision of methods of technical education had changed all this, and they were bringing the engineering profession into a position to meet the competition of the rest of the world.

Mr. J. A. F. ASPINALL advocated closer touch between the Universities and the workshop, and said if they could combine accurate scientific knowledge with practical work we could keep our position in the manufactories of the world

Dr. John Hopkinson was a happy illustration of this, as he had enabled a dynamo to be produced which was really a machine, not a toy, and which was almost as perfect as it was possible to be. It was gratifying to see how the great motor industry was spreading in this country. In 1896 the proprietors of the *Engineer* offered a prize of £100 to any makers of English motor cars who could show certain results at the Crystal Palace after a certain date. Sir Frederick Bramwell, Dr. Hopkinson and himself were asked to act as judges. There were only 21 entries when the time approached for the trials in 1897, and on the actual date of the trials only five cars turned up. After two days' trial the judges felt compelled to advise the proprietors of the *Engineer* not to award the prize, as there was not a single car which they could recommend. Happily all that was now changed. We had thousands of cars that had been manufactured in this country, and he hoped that this industry would be maintained, and that the work would continue to be done as well in the future as it had been done in the past. They had also to rejoice at the making of the internal combustion engine, and as long as they could get the public to take an interest in that class of work, so much the better it would be for the engineering trade.

Sir W. H. White in proposing "Prosperity to the Manchester Engineers" brought greetings and good wishes from all the Engineering Societies in London. He referred in the highest terms to Mr. Ashbury's interesting paper on "The Fifty Year's Work of the Association," and pointing out that in achieving the highest results there must be mutual help and assistance in all classes of work, for however excellent individual effort might be, it was to the combined interest of the members of the Association in their work that their prosperity would be ultimately continued.

THE CHAIRMAN in responding to the toast, made a special appeal to the wealthy engineers of Manchester that they should join in subscribing towards a Hall for their meetings. He believed that if they bought a block of buildings having shops underneath they would be able to pay a satisfactory dividend.

"Our Guests" was formally proposed by Mr. A. SAXON, and responded to by Mr. H. F. DONALDSON and Mr. J. GAVY, and the toast of the "Chairman" by Mr. T. ASHBURY, Past-President.

EXCURSIONS.

VISIT TO THE MANCHESTER SHIP CANAL, MAY 19TH, 1906.

On Saturday, the 19th May, on the invitation of the President (Mr. W. Henry Hunter) upwards of 350 members and lady friends made an inspection of the Manchester Ship Canal Docks.

The party assembled at the Pomona Docks, and were conveyed in steamers through various portions of the canal and docks. Unfortunately, a heavy downpour of rain prevented the complete carrying out of the programme. Before separating the party were hospitably entertained by the President in the new transport shed.

On the motion of Mr. R. Matthews (ex-president) a cordial vote of thanks was passed to Mr. W. Henry Hunter for his courtesy and generosity, and the proceedings terminated.

VISIT TO DERBY, JUNE 28TH, 1906.

On Thursday, the 28th of June, upwards of 60 members and lady friends visited Derby, for the inspection of the Royal Agricultural Show.

This party left the Central Station, Manchester, by the 9-20 train in special saloon carriages, and on arrival at Derby a substantial luncheon was served at the Midland Hotel.

Afterwards, the party proceeded in conveyances to the Show, where an enjoyable day was spent, the pleasures and interest being considerably enhanced by the presence of His Majesty, The King.

Subsequently, the party returned to the Midland Hotel, where tea was served, finally returning to Manchester by the 7-12 p.m. train.

The visit was in every way interesting and successful, although marred to some extent by bad weather throughout most of the day.

Visit to Newcastle-on-Tyne, August 30, 1906.

On Thursday, the 30th August, upwards of forty Members of the Association who had journeyed the previous evening to Newcastle-on-Tyne, by the courtesy respectively of Messrs. Swan, Hunter & Wigham Richardson Limited, and Messrs. The Wallsend Slipway and Engineering Company, had the opportunity of inspecting the famous Shipbuilding Yard at Wallsend-on-Tyne, and the interesting works of the Wallsend Slipway.

On arrival at the Shipbuilding Yard they were conducted through the various departments by Mr. Richardson, one of the Directors, and Members of the staff, and special opportunities were afforded to them of viewing the new Cunard turbine steamer "Mauritania," then in process of construction.

After leaving the Shipbuilding Yard Luncheon was partaken of. Subsequently the party visited the Wallsend Slipway, where every opportunity was given for them to view the various Turbines and Boilers being constructed for the "Mauritania," and other Engineering accessories, all of which were most interesting.

On the conclusion of the visit the party returned to Newcastle-on-Tyne, leaving the City for Manchester by the 4-40 p.m. train. Dinner being served *en route*

The visit in every way was interesting and successful, and seemed to give great pleasure to all of the members who had the opportunity of being present.

OPENING OF 51st DISCUSSION SESSION.

October 17th, 1906.

The 51st Discussion Session of the Association was inaugurated by a conversazione held at the Municipal Art Gallery, Manchester, on Wednesday evening, 17th October. On this occasion the President (Mr. W. Henry Hunter) and Mrs.

Hunter invited the members and lady friends to the Conversazione, and upwards of 450 accepted the invitation.

The Guests were courteously received by the President and Mrs. Hunter.

During the evening the Band of the 2nd Vol. Bat. Manchester Regiment gave an excellent programme of music, and in another room of the Gallery a capital vocal programme was given by a Quartette Party including Madam Annie Walker, Miss Jessie Young, Mr. Walter Lawley, and Mr. Cuthbert Allan, while at intervals Mr. Ernest Hastings gave amusing selections from his repertoire.

Refreshments were served to the guests during the proceedings, and altogether a pleasant and enjoyable evening marked the opening of the session.

LIBRARY.

The Association exchanges Transactions with the following :—

American Institute of Mining Engineers.
,, Society of Mechanical Engineers.
,, ,, Civil ,,
Canadian Society of Civil Engineers.
Engine, Boiler, and Employers' Liability Insurance Company.
Franklin Institute, America.
Gas Institute, Incorporated.
Institution of Civil Engineers of England.
,, Engineers and Shipbuilders in Scotland.
,, Mechanical Engineers.
Iron and Steel Institute.
Liverpool Engineering Society.
Manchester Geological Society.
,, Literary and Philosophical Society.
Midland Institute of Mining, Civil and Mechanical Engineers.
North of England Institute of Mining and Mechanical Engineers.
North East Coast of Engineers and Shipbuilders.
South Wales Institute of Engineers.

The following publications are received periodically :—

Cassier's Magazine.
Engineer.
Engineering.
„ Times.
„ Review.
Iron and Steel Trades' Review.
Marine Engineer.
Mechanical World.
„ Engineer.
Page's Weekly.
Practical Engineer.
Textile Mercury.
„ Manufacturer.

OBITUARY.

John Bates joined the Association as an ordinary Member in the year 1880.

He held various important positions as foreman moulder, one of his last engagements in that capacity being with the National Gas Engine Co. of Ashton-under-Lyne.

He died on the 26th of May, 1906, in the sixty-ninth year of his age.

William Craven was born at Bradford, Yorkshire, on 8th August, 1829. In his early youth he went to Manchester, and served his apprenticeship with Messrs. Sharp, Roberts, & Co., on its completion he was employed at Messrs. Fairbairn's Work's. In 1853 he commenced business in partnership with his brother—Mr. Greenwood Craven—as machine tool makers at Dawson Croft Mill, Salford. The requirements of the business very soon necessitated removal to larger premises in Manchester, where they were joined by their brother—Mr. John Craven. In consequence of a still further and rapid increase in

the demand for their high-class machine tools, land was bought in 1863, and new works were built in Osborn Street, the site of the present works.

In the development of the business each of the three brothers assumed responsibility for one particular portion of it, William Craven taking charge of the designing of the various machines constructed by the firm, and in this department he made his name famous in the engineering profession. In 1875 the manufacture of cranes was taken up, and so great has this branch grown that in 1900 new works were built at Reddish, near Stockport, specially equipped for their manufacture together with that of modern machine-tools. In 1885 the firm was transformed into a limited company, with Mr. Greenwood Craven as Chairman, who was succeeded on his death in 1889 by Mr. William Craven. He retained his position until advancing age and failing health led him to resign in 1903, when his son—Mr. W. H. S. Craven—was elected chairman. He took little part in public affairs, devoting his time and abilities to his profession. His death took place at his residence at St. Anne's-on-the-Sea, Lancashire, on 10th May, 1906, in his seventy-seventh year.

He became a member of the Association in 1880.

William Knowles served his apprenticeship with the firm of Mr. William Sharples, of Ramsbottom, on the termination of which he worked for about eight years as journeyman. Subsequently he entered into partnership with Mr. Pickup, engineering machinist, of Pendleton, forming the firm of Messrs. Pickup & Knowles, with which he was connected at the time of his death, which took place on 20th November, 1906, in the 55th year of his age.

He was elected an Honorary Member of the Association in 1902.

J. E. MATHEWSON was Managing Director of the joint firms of Tilghman's Patent Sandblast Company, Limited, and George Richards & Co., Limited, machine tool makers, Broadheath. He introduced into England from America the sandblast process. The idea of the sandblast apparatus was originated by the late General B. C. Tilghman, and Mr. Mathewson, who made the first apparatus, was sent to England to exhibit the process at the South Kensington Exhibition in 1873. From that time he remained in England, and on the formation of Tilghman's Patent Sandblast Company in 1874 he was made manager of the engineering department. Three years later he became managing director of the firm, which was afterwards established in Sheffield. Ten years ago the works were removed to Broadheath, where the engineering works of Messrs. George Richards & Co., Limited, were acquired. Since that time Mr. Mathewson had been the managing director of both undertakings.

He was elected an Honorary Member of the Association in 1898, and died May 31st, 1906.

SAMUEL RENDELL was born at Clifton, Bristol, on 3rd November, 1857, and was educated at Chesterfield Grammar School. His apprenticeship was served in the shops and drawing office of Messrs. R. & W. Hawthorn, Leslie & Co., Newcastle-on-Tyne. While there, in 1876, he obtained a local scholarship at the evening classes of the Newcastle Mechanics' Institute, which enabled him to attend the day classes in engineering at Owens College, Manchester, where he remained four years. In October, 1880, he entered the drawing office of Messrs. Beyer, Peacock & Co., of Gorton, as junior draughtsman, rising to be assistant chief draughtsman and finally to chief draughtsman. His mathematical knowledge frequently found application in mechanical scheming and solving problems of

locomotive design. His death took place at New Mills, near Stockport, on 29th March, 1906, at the age of forty-eight.

He became a Member of the Association in the year 1893.

David Rodger was born at Largs, in Ayrshire, Scotland, and served his apprenticeship as a blacksmith in an agricultural implement shop; he was twenty years of age when he came to England and worked at Rochdale for a considerable time as a working foreman blacksmith. He then moved to Manchester, where he worked for many years for the late Sharp, Stewart, locomotive builders. He afterwards removed to Bristol, to take over the control of the smith and forge department of the Havonside Engine Works, and after serving that firm for several years he removed to Barrow to be foreman over the engine, smithy, and permanent way department of the Furness Railway Co. whom he served with great credit for 23 years or thereabouts. He was highly respected by all who came into contact with him, both at work and in social life. He retired from his duties about three years ago and he died on June 15th, 1906, aged 77 years.

He was elected an ordinary member in 1880.

Ezra Sykes received his training with the firm of Messrs. John Sykes & Sons, Huddersfield, subsequently becoming a senior partner in the same firm.

He was elected an honorary member of the Association in 1892, and died on the 1st of January, 1906.

Francis William Webb, formerly chief mechanical engineer of the London and North-Western Railway Company, died at Bournemouth on Monday evening, the 4th June, at the age of 71 years. Mr. Webb was the son of a Staffordshire clergyman, and in early life became a pupil at Crewe railway works, under

Mr. Trevethick, the son of the "father of the locomotive." After serving an apprenticeship there he was appointed manager of the Bolton Iron and Steel Company's works, where he remained about five years.

He then returned to Crewe, and succeeded the late Mr. Ramsbottom as manager of the Crewe Works and chief mechanical engineer of the London and North-Western Railway Company. From 1871 until 1890 he retained that position, extending the works over a large area, and practically concentrating all the locomotive departments at Crewe, where he controlled a staff of over 19,000 men. During his regime at Crewe he turned out 4,000 locomotive engines. The works at Crewe produced everything that was needed for the equipment of a railway, from a porter's hand-lamp to the leviathan locomotive. He introduced many improvements into the locomotive, his name coming into great prominence in the railway world through his building so many express engines on the "compound" principle. He was also associated with Mr. A. M. Thompson in the improvement of the signalling apparatus.

He was for many years President of the Crewe Mechanics' Institute, which has turned out many eminent railway engineers who are filling responsible positions all over the world. Mr. Webb was the Mayor of Crewe in the Jubilee year of Queen Victoria, and he was one of the first freemen of the borough, a county alderman, a county magistrate for Cheshire, and a borough magistrate for Crewe. He retired from the London and North-Western service a few years ago.

He became a Life Member of this Association in 1882.

Thomas Whitehead was born at Belturbet, County Ulster, Ireland, Feburary 18th 1849. His education was received at the City of London School and other schools. He served his apprenticeship from 1865 to 1871, in the shops of Messrs.

Cowans, Sheldon, & Co. He was next engaged as draughtsman in the works of Pearson & Knowles, Coal & Iron Co., of Warrington, until 1876 in which year he was appointed to superintend the erection of extensive wire and rolling mill plant in the Warrington district, which appointment continued until 1888.

He then became engineer to the Broughton Copper Co., of Manchester, remaining in that position until his death which took place at Broughton, Manchester, June 12th, 1906, at the age of 57.

He was elected an honorary member of the Association in 1898.

TREASURER'S GENERAL CASH ACCOUNT, for the Year ending 31st December, 1906.

Dr. (Including Superannuation Fund Account.) **Cr.**

1906—Jan. 1 to Dec. 31.			£	s.	d.
To Balance as per last Report			5,437	7	11
,, Contributions and Entrance Fees			804	15	6
,, Interest from Mortgages on Properties		£75 7 6			
,, ,, Leeds Corporation 3½ % Stock		19 19 0			
,, ,, Manchester Corporation 3½ % Loan		28 5 6			
,, ,, Blackpool Corporation 3⅜ % ,,		17 4 7			
,, ,, ,, 3½ % ,,		28 5 6			
,, ,, Bury Corporation 3½ % ,,		4 1 1			
,, ,, Bank		8 7 7			
			171	10	9
,, Transactions sold			2	5	0
			£6,415	19	2

Audited and found correct,

W. LEES,
J. MITTON, } AUDITORS.

19th March, 1907.

1906—Jan. 1 to Dec. 31.			£	s.	d.
By Rent—Grand Hotel			20	0	0
,, Secretary's Salary			150	0	0
,, Librarian's ,,			16	0	0
,, Superannuation Allowances			176	0	0
,, Funeral Allowances—Messrs. S. Bendall, D. Rodger, and J. Bates			30	0	0
,, Printing and Lithography (Transactions)	£235 5 0				
,, Binding of do.	30 10 0				
,, Members' Lists	20 5 0				
,, General Circulars and Miscellaneous Work	46 14 0				
,, Stationery	9 18 6				
			342	12	6
,, Delivery of Transactions			6	8	0
,, Annual Dinner Expenses			23	2	1
,, Chamber of Commerce			2	2	0
,, Excursion Expenses			8	19	10
,, Heywood, Ltd., John, *re* Library Volumes			13	5	11
,, Council and Sub-Committee Expenses	£33 18 4				
,, Postages, Circulars, and Correspondence	51 8 6				
,, Sundries	27 13 4				
			112	15	2
,, Cash invested in Properties: Mortgages	£1,350 0 0				
,, ,, ,, Leeds Corporation, 3½ % Stock	600 0 0				
,, ,, ,, Premium on do.	90 6 6				
,, ,, ,, Man'ter Corpor'tion, 3½ % Loan	700 0 0				
,, ,, ,, Blackpool ,, 3⅜ % ,,	500 0 0				
,, ,, ,, ,, ,, 3½ % ,,	700 0 0				
,, ,, ,, Bury ,, 3½ % ,,	500 0 0				
			4,440	6	6
,, Cash in Bank	1,055 17 8				
,, ,, Treasurer's hands	6 16 6				
,, ,, Secretary's ,,	11 13 5				
			1,074	7	2
			£6,415	19	2

The above Cash Account shows a surplus of Receipts over Expenditure on the year's working of £77. 5s. 9d. and a Cash Balance to the Credit of the Association of £5,514. 13s. 8d.

SUPERANNUATION FUND ACCOUNT, for Year ending 31st December, 1906.

Dr. (Included in General Account.) **Cr.**

1906—Jan. 1 to Dec. 31.	£	s.	d.
To Capital invested as per Rule passed December, 1901	5,000	0	0
,, Twelve Months' Interest on above Capital invested as per Rule	171	10	9
,, Draft from General Account	4	9	3
	£5,176	0	0

1906—Jan 1 to Dec. 31.	£	s.	d.	£	s.	d.
By Superannuation Allowances:—						
Mr. John Meller	20	16	0			
,, John Dutton	20	16	0			
,, J. Errock	20	16	0			
,, J. G. Cochrane	20	16	0			
,, J. Glennie	20	16	0			
,, D. Rodger (deceased)	9	12	0			
,, W. H. Beastow	20	16	0			
,, P. Ward	20	16	0			
,, W. Lawson	20	16	0			
				176	0	0
,, Balance to Credit of Superannuation Fund Account				5,000	0	0
				£5,176	0	0

Audited and found correct,

19th March, 1907

W. LEES,
J. MITTON, } AUDITORS.